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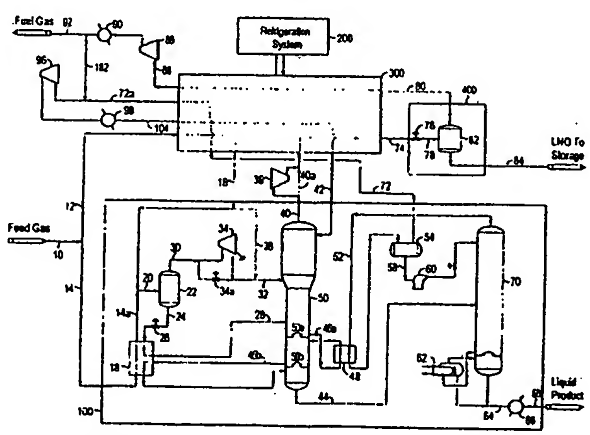
(54) Title: ENHANCED NGL RECOVERY UTILIZING REFRIGERATION AND REFLUX FROM LNG PLANTS



(57) Abstract: The present invention is directed to methods and apparatus for improving the recovery of the relatively less volatile components (68) from a methane-rich gas feed (10) under pressure to produce an NGL product (68) while, at the same time, separately recovering the relatively more volatile components which are liquefied to produce and LNG product (84). The methods of the present invention improve separation and efficiency within the NGL recovery column while maintaining column pressure to achieve efficient and economical utilization of the available mechanical refrigeration (200). The methods of the present invention are particularly useful for removing cyclo-hexane, benzene and other hazardous, heavy hydrocarbons from a gas feed. The benefits of the present invention are achieved by the introduction to the NGL recovery column (50) of an enhanced reflux (42) lean on the NGL components. Further advantages can be achieved by thermally linking a side reboiler (48) for the NGL recovery column (50) with the overhead condenser (52)for the NGL purifying column (70). Using the methods of the present invention, recoveries of propane and heavier components in excess of 95 % are readily achievable.

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ENHANCED NGL RECOVERY UTILIZING REFRIGERATION AND REFLUX FROM LNG PLANTS

Background of the Invention

Field of the Invention

The present invention relates generally to methods and apparatus for high recovery of hydrocarbon liquids from methane-rich natural gases and other gases, e.g., refinery gases. More particularly, the present invention provides methods and apparatus for more efficiently and economically achieving high recovery of ethane, propane, propylene and heavier hydrocarbon liquids (C_{2+} hydrocarbons) in association with liquefied natural gas production.

Description of the Background

Due to its clean burning characteristics and the implementation of more stringent environmental regulations, the projected demand for natural gas has been increasing during recent years. In addition to methane, natural gas includes some heavier hydrocarbons and impurities, e.g., carbon dioxide, nitrogen, helium, water and non-hydrocarbon acid gases. After compression and separation of these impurities, natural gas may be further processed to separate and recover heavier hydrocarbons as natural gas liquids (NGL's) thereby producing pipeline quality methane. The pipeline quality methane is then delivered to gas pipelines as the sales gas ultimately transmitted to end-users.

In the case of remote gas production or distant gas markets, transportation of produced natural gas via gas pipeline might not be economical or even feasible. Accordingly, liquefaction of natural gas has become a viable and widely adopted scheme. The economics of liquefying natural gas is feasible due mainly to the great reduction in volume as the gas is converted to a liquefied state, making it easy to store and transport. Another advantage of converting the produced natural gas to a liquefied form is that the produced LNG can be economically stored to supplement energy suppliers during seasonal peak demand periods. Liquefied natural gas, typically stored at near atmospheric pressure and at temperatures of about –260° F, is transported to distant markets via refrigerated tankers.

Processes for the liquefaction of natural gas are well known in the art. Natural gas

comprising predominantly methane enters a LNG plant at elevated pressures and is pretreated to produce a purified feed stock suitable for liquefaction at cryogenic temperatures. The pretreatment typically includes removal of acid gases, e.g., hydrogen sulfide and carbon dioxide, together with other contaminants, including moisture and mercury. The purified gas is thereafter processed through a plurality of cooling stages using indirect heat exchange with one or more refrigerants to progressively reduce its temperature until total liquefaction is achieved. The pressurized liquid natural gas is sub-cooled to reduce flashed vapor through one or more expansion stages to final atmospheric pressure suitable for storage and transportation. The flashed vapor from each expansion stage, together with the boil off gas produced as a result of heat gain, are collected and used as a source of plant fuel gas with any excess recycled to the liquefaction process.

Because a significant amount of refrigeration energy is required for liquefying natural gas, the refrigeration system becomes one of the major units in a LNG facility. Mechanical refrigeration cycles mostly in closed circuit are often employed in LNG projects. A number of liquefaction processes have been developed with the differences mainly found in the refrigeration cycles used. The most commonly used LNG processes can be classified into three categories as follows:

1) The cascade process presents the benefits of easy start-up and easy shutdown. The cascade process consists of successive refrigeration cycles using propane, ethane or ethylene, and methane. The thermal efficiency can be readily enhanced by the use of multi-stage compressors. United States Patent No. 5,669,234, incorporated herein by reference, represents an exemplary cascade process.

2) The propane pre-cooled mixed refrigerant process involves the use of a multi-component mixture of hydrocarbons, typically comprising propane, ethane, methane, and optionally other light components in one cycle, and a separate propane refrigeration cycle to provide pre-cooling of natural gas and the mixed refrigerant to about –35°F. The propane mixed refrigerant process advantageously provides improved thermal efficiency. However, a significant disadvantage results from the use of extremely large spiral wound exchangers. Such exchangers are a long lead item requiring special facilities in the field to manufacture. Examples of the propane mixed refrigerant process

include those disclosed in United States Patent Nos. 4,404,008 and 4,445,916, incorporated herein by reference.

3) The single, mixed refrigerant process includes heavier hydrocarbons, e.g., butanes and pentanes, in the multi-component mixture and eliminates the pre-cooled propane refrigeration cycle. It presents the simplicity of single compression in the heat exchanger line and is particularly advantageous for small LNG plants. United States Patent No. 4,033,735, incorporated herein by reference, represents an exemplary single, mixed refrigerant process.

The use of a turbo expander in combination with mechanical refrigeration cycles has also been adopted in many LNG processes. Examples of the use of a turbo expander are disclosed in United States Patent Nos. 3,724,226; 4,065,278; 5,755,114;4,970,867, 5,537,827; and Int'l Patent No. WO 95/27179.

In addition to methane, natural gas typically contains various amounts of ethane, propane and heavier hydrocarbons. The composition varies significantly depending on the source of the gas and gas reserve characteristics. Hydrocarbons heavier than methane need to be removed from LNG for various reasons. Hydrocarbons heavier than pentane, including aromatics, having high freezing points must be reduced to an extremely low level to prevent the freezing and plugging of process equipment in the course of the cooling and liquefaction steps. After separation of these heavy components from LNG, they provide excellent gasoline blending stock. Many patents have been directed to methods for removal of these heavy hydrocarbons. For instance, United States Patent No. 5,325,673 discloses the use of a single scrub column in the pretreatment step operated substantially as an absorption column to remove freezable C_{5+} components from a natural gas stream feeding to an LNG facility. The recovered heavy liquid can subsequently be fractionated into various fractions for use as make-up refrigerants. United States Patent No. 5,737,940 describes an exemplary system incorporated in a cascade process.

Besides being liquefied as part of LNG and used as fuel, lighter natural gas liquid (NGL) components, e.g., hydrocarbons having 2-4 carbon atoms, can also be a source of feedstock to refineries or petrochemical plants. Therefore, it is often desirable to maximize the recovery of NGL to enhance revenue. To achieve high recovery of these components, it is common practice to design an NGL recovery plant so that the tail gas

produced by the NGL recovery plant and comprising primarily methane is delivered to the LNG facility for liquefaction. United States Patent Nos. 5,291,736 and 5,950,453 are typical examples of such combined facilities.

Among several different NGL recovery processes, the cryogenic expansion process has become the preferred process for deep hydrocarbon liquid recovery. In a conventional turbo-expander process, the feed gas at elevated pressure is pretreated for the removal of acid gases, moisture and other contaminants to produce a purified feed stock suitable for further processing at cryogenic temperatures. The purified feed gas is then cooled to partial condensation by heat exchange with other process streams and/or external propane refrigeration, depending upon the richness of the gas. The condensed liquid after removal of the less volatile components is then separated and fed to a fractionation column, operated at medium or low pressure, to recover the heavy hydrocarbon constituents desired. The remaining non-condensed vapor portion is turbo-expanded to a lower pressure, resulting in further cooling and additional liquid condensation. With the expander discharge pressure typically the same as the column pressure, the resultant two-phase stream is fed to the top section of the fractionation column where the cold liquids act as the top reflux to enhance recovery of heavier hydrocarbon components. The remaining vapor combines with the column overhead as a residue gas, which is then recompressed to a higher pressure suitable for pipeline delivery or for liquefaction in an LNG facility after being heated to recover available refrigeration.

Because a column operated as described above acts mainly as a stripping column, the expander discharge vapor leaving the column overhead that is not subject to rectification still contains many heavy components. These components could be further recovered through an additional rectification step. Ongoing efforts attempting to achieve a higher liquid recovery have mostly concentrated on the addition of a rectification section and the generation of an enhanced reflux stream to the expanded vapor. Many patents exist purporting to disclose an improved design for recovering ethane and heavier components in an NGL plant. For example, see United States Patent Nos. 4,140,504; 4,251,249; 4,278,457; 4,657,571; 4,690,702; 4,687,499; 4,851,020; and 5,568,737. At best, these processes are capable of recovering 95%+ of ethane and heavier hydrocarbons. However, they typically involve a significant capital expenditure during construction of

the NGL plant as well as increased operational costs during its lifetime.

It will be recognized that all NGL components have higher condensing temperatures than methane so that all will be liquefied in the course of operating a LNG process. A substantial cost savings may be realized, if the NGL recovery could be effectively integrated within the liquefaction process instead of building a separate facility.

Recovery of NGL in the LNG facility has also been suggested in the literature. For example, it has been suggested that lighter NGL components could be recovered in conjunction with the removal of C_{5+} hydrocarbons by using a scrub column in a propane pre-cooled, mixed refrigerant process. See United States Patent Nos. 4,445,917 and 5,325,673. A cryogenic stripping column in a cascaded process was suggested in United States Patent No. 5,737,940 for recovery of heavy hydrocarbons from a natural gas feed stream. In a further modification, United States Patent Nos. 5,950,453 and 5,016,665 disclose a method wherein a demethanizer is incorporated in the process for liquefying natural gas for recovering heavier hydrocarbon liquids.

The NGL recovery column in these systems is often required to operate at a relatively high pressure, typically above 550 psig, in order to maintain an efficient and economical utilization of mechanical refrigeration employed in the LNG process. While benefitting from lower refrigeration energy by maintaining a high liquefaction pressure, the separation efficiency within the recovery column may be significantly reduced due to less favorable separating conditions, i.e., lower relative volatility inside the column. In addition, prior art processes fail to effectively provide reflux to the recovery column. As a result, none of these processes are capable of efficiently maintaining a high NGL recovery, i.e., the NGL recovery does not typically exceed 80% with these processes.

As can be seen from the foregoing description, those skilled in the art have long sought methods and apparatus for improving the efficiency and economy of processes for separating and recovering ethane and heavier natural gas liquids in an NGL plant. While prior art methods have been capable of recovering more than 95% of the ethane and heavier hydrocarbons in a stand-alone NGL recovery plant, those processes fail to maintain the same recovery when integrated with a LNG facility. Accordingly, there has been a long felt but unfulfilled need for more efficient, more economical methods of

integrating these processes while improving, or at least maintaining, their economics.

SUMMARY OF THE INVENTION

The present invention provides an integrated process for recovery of the components of a feed gas containing methane and heavier hydrocarbons while maximizing NGL recovery and minimizing capital expenditures and operating costs incurred with the LNG facility. The present invention is also intended to improve separation efficiency within an NGL recovery column while maintaining column pressure as high as practically possible to achieve an efficient and economical utilization of mechanical refrigeration in the liquefaction process. This is achieved by the introduction of an enhanced reflux specifically suitable for the purpose of the recovery column.

Historically, the price of liquid ethane has been cyclical, rising and falling in response to the demand for use as petrochemical feed stock. When the price of liquid ethane is high, gas processors can generate additional revenues by increasing the recovery of ethane. On the other hand, when the ethane market is depressed, it may be desirable to effectively reject ethane, allowing it to remain in the LNG, but still maintain high recovery of propane and heavier components. Due to the cyclical nature of the liquid ethane market, designing a facility which can selectively and efficiently recover or reject ethane will allow producers to quickly respond to changing market conditions, a phenomenon that seems to occur ever more frequently in today's market. Accordingly, the present invention is designed to permit flexible transition between operation for ethane recovery or ethane rejection.

A number of liquefaction processes developed in the prior art have been described above. These processes may differ significantly depending on the mechanical refrigeration cycle used. The methods of the present invention may be integrated with any of those processes. The methods of the present invention are applicable independent of the type of mechanical refrigeration used in the liquefaction process. However, certain of the methods may be more easily integrated into certain liquefaction processes

The present invention, in the broadest sense, provides an integrated process and apparatus for cryogenically recovering ethane, propane and heavier components during natural gas liquefaction processes via a distillation column, in which the reflux derived from various sources in the liquefaction process is essentially free of the components to

be recovered. The provision of an enhanced reflux stream, which is lean on the NGL components, to the distillation column permits a high recovery of NGL components even when the column is operated at a relatively high pressure. The process involves introducing a cooled gas or condensate (i.e., two phase) feed stream into a first distillation column, e.g., an NGL recovery column, at one or more feed trays. The gas or condensate feed stream is separated into a first liquid stream primarily comprising NGL components to be recovered and a methane-rich overhead stream essentially free of NGL components. The methane-rich overhead stream is further cooled to total liquefaction and is preferably sub-cooled. This liquefied, and preferably sub-cooled, methane-rich stream under pressure is subsequently flashed to near atmospheric pressure in one or more steps with the LNG stream collected in the final flash step being delivered to the LNG tank for storage. The flashed vapor stream or streams are heated and compressed to a higher pressure for delivery as a fuel gas stream. Excess flashed vapor, if any, is recycled to the liquefaction process in which it is ultimately liquefied as pressurized LNG stream or a reflux stream for the NGL recovery column. The first liquid stream (i.e., the liquid stream produced by the NGL recovery column) is introduced into a second distillation column, e.g., an NGL purifying column, at one or more feed trays. In the second column, the first liquid stream is separated into an NGL product stream produced from the bottom and a first vapor portion stream primarily comprising all of the remaining lighter components from the overhead.

In one embodiment of the present invention, the first vapor portion stream and optionally, a portion of the excess flashed vapor stream are combined. The combined stream is compressed and cooled to substantial condensation and thereafter introduced to the top of the NGL recovery column as a reflux stream. This reflux stream will contain an extremely low concentration of the heavy components to be recovered in the NGL product stream. This stream enhances the recovery efficiency within the column and reduces the loss of NGL components in the methane-rich overhead stream to a minimum. A high NGL recovery is therefore achieved even with a relatively high operating pressure, i.e., a pressure of about 600 psig, for the NGL recovery column.

The economic advantages of the present invention can be further improved by thermally linking a side reboiler for the first distillation column with the overhead

condenser for the second distillation column. More specifically, the first vapor portion stream is cooled in countercurrent heat exchange with a liquid stream withdrawn from a tray located below the feed trays of the first distillation column. The cooled first vapor portion stream is separated into a liquid fraction for introduction into the second distillation column as a top reflux stream and a lighter, vapor fraction with further reduced NGL components which is liquefied alone or upon combination with a portion of the excess flashed stream and introduced into the first distillation column as a top reflux. Thus the NGL recovery efficiency in the second column is enhanced. Heat is transferred from the NGL purification column to the NGL recovery column by the above-cited liquid stream which is withdrawn and returned to the NGL recovery column where it provides a stripping action in the bottom portion of the column, thereby reducing volatile components, e.g., methane, in the first liquid stream from the bottom.

The recovery efficiency can be improved in another embodiment of the present invention by the introduction of a second reflux stream to the upper, rectification section of the first distillation column. The second reflux stream enters the distillation column preferably in the middle of the rectification section, as a middle reflux stream which provides a bulk rectification effect and reduces the NGL components to be recovered in the up-flow vapor stream. Residual NGL components in the upward vapor stream are efficiently recovered via the first reflux stream (i.e., top reflux stream). A slipstream from the feed gas stream can be taken and cooled to substantial condensation or even sub-cooled to form the second reflux stream. In some cases, the feed gas stream contains much heavier components, e.g., hexane and aromatics, which tend to freeze at cryogenic temperatures. The feed gas stream can be first cooled to partial condensation where most of these components will be condensed in the liquid phase and separated out in a separator. Such resulting liquid stream can be fed to the lower section of the NGL recovery column or combined with a stream being routed to the lower section of the NGL recovery column. A slipstream can then be taken from the non-condensed vapor portion and further cooled to substantial condensation to form the second reflux stream. Optionally, this reflux stream can be fed to the top of the NGL recovery column either as a separate stream or in combination with the previously described top reflux or first reflux stream. In another embodiment, the second reflux stream as described herein can

function as the sole reflux stream to the column and can be fed to the top of the NGL recovery column.

Another feature providing a significant economic advantage in the present invention is the cooling of a portion of the feed gas stream by countercurrent heat exchange with a refrigerant stream comprising a portion of the first liquid stream (i.e. liquid withdrawn from the lower portion of the first distillation column). As a result, the refrigerant stream is partially vaporized and may be separated into a second liquid stream for introduction into the second distillation column and a second vapor stream for introduction into the first distillation column as a stripping gas stream for compression and cooling. The introduction of stripping gas stream supplements the heat requirements in the first distillation column for stripping volatile components from the in-situ liquid stream. It also enhances the relative volatility of the key components and, accordingly, the separation efficiency in the column, particularly when the column is operated at a relatively high pressure as in the NGL recovery column of the present invention.

In yet another embodiment of the present invention, the top reflux stream to the first distillation column is generated by recycling a small portion of the pressurized LNG stream prior to flashing. This reflux stream has an extremely low content of the NGL components to be recovered and, accordingly, enhances separation efficiency. This reflux scheme can be advantageous for the liquefaction process where the LNG can be deeply sub-cooled using very cold mechanical refrigeration to reduce the vapor produced in the flashing steps to a minimum. Typical examples of this embodiment include liquefaction processes using mixed refrigerant with or without propane pre-cooling and cascaded refrigeration in a closed circuit.

In another embodiment of this invention which provides for highly efficient removal of the C5 and heavier components from the gas stream to be liquefied, the reflux stream to the NGL recovery column is provided in accordance with any of the methodologies set forth herein but the stripping gas stream employed in the NGL recovery column is provided via a portion of the feed gas stream rather than the vaporization of a portion of the liquid existing in or removed from the NGL recovery column either by one or more internal or external reboilers. The portion of the feed gas stream can be fed either directly into the column or first cooled via indirect heat exchange

with the first liquid stream which is produced from the bottom of said column. In the later mode, additional cooling via the first liquid stream is possible by first flashing the first liquid stream to a pressure slightly above the operating pressure of the NGL purification column.

The methods and apparatus of the present invention efficiently integrate NGL recovery into the natural gas liquefaction process and permit high recoveries of propane and heavier components, e.g., recoveries exceeding 95% of those components originally present in the feed gas. Certain of the embodiments when properly optimized permit the recovery of at least 99% of the propane and heavier hydrocarbons originally found in the feed gas. The high recovery of heavier hydrocarbons achieved with the methods of the present invention may be advantageously used to clean gas feeds contaminated by cyclo-hexane, benzene and other heavy hydrocarbons which have been determined to create potential freezing problems and, accordingly, must be thoroughly removed. This high NGL recovery is achieved while eliminating the NGL plant, as typically employed in the prior art, in the front-end of the LNG facility. Thus, significant savings of capital, as well as operating costs, are achieved. In addition, the flexible design of the present invention permits an easy transition between operations designed to either recover or reject ethane in order to accommodate rapidly changing values of liquid ethane. The integration methods proposed in the present invention can also be easily adapted for use with any liquefaction process regardless the refrigeration system used.

BRIEF DESCRIPTION OF THE DRAWINGS

The application and advantages of the present invention will become more apparent by referring to the following detailed description in connection with the accompanying drawings, wherein:

Fig. 1 illustrates a schematic representation of an enhanced NGL recovery process utilizing refrigeration and reflux from a LNG plant wherein a top reflux stream to the NGL recovery column is employed;

Fig. 2 illustrates a schematic representation of a LNG plant employing a typical open cycle cascaded refrigeration process with enhanced NGL recovery;

Fig. 3 illustrates a schematic representation of a LNG plant employing a typical propane pre-cooled, mixed refrigeration process with enhanced NGL recovery;

Fig. 4 illustrates a schematic representation of a LNG plant employing a typical single, mixed refrigeration process with enhanced NGL recovery;

Fig. 5 illustrates an alternative embodiment of an enhanced NGL recovery process utilizing refrigeration and reflux from a LNG plant and a second reflux stream to the NGL recovery column;

Fig. 6 illustrates an alternative embodiment of an enhanced NGL recovery process utilizing refrigeration and reflux from a LNG plant wherein the reflux to the NGL recovery column is a portion of the liquefied natural gas recycled under pressure;

Fig. 7 illustrates an alternative embodiment of an enhanced NGL recovery process utilizing refrigeration and reflux from a LNG plant wherein the feed gas is employed as a stripping gas in the NGL recovery column;

Fig. 8 illustrates an alternative embodiment of an enhanced NGL recovery process utilizing refrigeration and reflux from a LNG plant wherein the generation of a stripping gas from column liquid in the NGL recovery column is enhanced; and

Fig. 9 illustrates another alternative embodiment of an enhanced NGL recovery process utilizing refrigeration and reflux from a LNG wherein a simplified NGL purifying system is employed.

While the invention will be described in connection with the presently preferred embodiments, it will be understood that this is not intended to limit the invention to those embodiments. To the contrary, it is intended to cover all alternatives, modifications and equivalents as may be included in the spirit of the invention as defined in the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

The present invention permits the separation and recovery of substantially all of the NGL components, i.e., ethane, propane and heavier hydrocarbons, from a compressed natural gas in a LNG process. The present invention achieves these high recoveries while eliminating the need for a separate NGL plant in the front-end of the LNG facilities by introducing to the distillation column an enhanced reflux having an extremely low content of the NGL components to be recovered. The introduction of lean reflux permits the column to be operated at higher pressures while still maintaining high recovery of NGL and, accordingly, the refrigeration system can be utilized more efficiently in the

liquefaction process. As a result of this more efficient integration, the capital requirements, as well as operating costs, for recovering substantially all of the NGL components present in the feed gas in a LNG process may be greatly reduced.

The foregoing merely provides an exemplary description of the use of the present invention in a conventional system for liquefying inlet gas and should not be considered as limiting the methods of the present invention. While various values of temperature, pressure and composition are recited in association with the specific examples described, those conditions are approximate and merely illustrative, and are not meant to limit the invention. For purposes of this invention, when the term *lean* reflux is used with respect to a distillation column, it refers to the components to be recovered in the bottom liquid stream. For example, a *lean* reflux for recovery of propane and heavy hydrocarbons means that the reflux stream has a low content of the cited components. Furthermore, with respect to the terms *upper* and *lower* as used with respect to a distillation column, these terms are to be understood as relative to one another, i.e., that withdrawal of a stream from an *upper* region of a column is at a higher position than a stream withdrawn from a *lower* region thereof. In an exemplary, but non-limiting embodiment, *upper* may refer to the upper half of a column, whereas *lower* may refer to the lower half of a column. In another embodiment, where the term *middle* is used, it is to be understood that a middle region is intermediate to an *upper* region and a *lower* region. However, where upper, middle, and lower are used to refer to a cryogenic distillation column, it should not be understood that the column is strictly divided into thirds by these terms.

<u>Embodiment Depicted in Figure 1</u>

Fig. 1 illustrates a schematic configuration of one exemplary embodiment of the invention where at least about 95%, preferably above 98%, of the propane, propylene and heavier hydrocarbons, i.e., the C_{3+} hydrocarbons, from a feed gas which will be ultimately liquefied as LNG product may be recovered. Referring to Fig. 1, a dry feed gas at a flow rate of about 480 MMSCFD is introduced into the illustrated process through inlet stream 10 at a pressure of about 1015 psia and a temperature typically close to ambient, for example about 100°F in this illustration.

As a point of clarity, reference to a given stream number implies that a physical conduit exists wherein said stream can flow from one location to another, such conduit

including but not limited to pipe, tubing, heat exchangers and other containing vessels through which a fluid may flow. Dry feed gas stream 10 has been pre-treated as necessary to remove undesirable components, including acid gases, mercaptans, mercury and moisture, from the natural gas delivered to the facility. Stream 10 is split into two streams 12 and 14. The smaller portion, stream 14, is directed through gas/liquid exchanger 18 in NGL recovery block 100 where it is in countercurrent heat exchange with liquid withdrawn from the bottom of NGL recovery column 50 and liquid from separator 22. This inlet gas provides heat for NGL recovery column 50, while chilling the inlet gas to a temperature of about –61°F. The larger portion of inlet gas, stream 12, flows to exchanger block 300 where it is cooled to about –40°F by utilizing refrigeration in the liquefaction process. The cooling steps in the refrigeration system used in the liquefaction process may differ significantly, depending on the process used, and are collectively illustrated as simplified exchanger block 300, which will be described in more detail later.

Cooled feed gas stream 16 from exchanger block 300 is combined with the cooled feed gas stream 14a from gas/liquid exchanger 18. The combined stream 20 at about –42°F and 990 psia is directed and separated into liquid stream 24 comprising any condensed heavier hydrocarbons and into cooled vapor stream 30 comprising lighter and more volatile components in separator 22. Liquid stream 24 is expanded through expansion device 26 and preheated in gas/liquid exchanger 18 prior to introduction into a distillation column, e.g., NGL recovery column 50, as stream 28 for further fractionation. Depending upon feed gas composition and overall refrigeration, the preheating of expanded liquid stream 24 in exchanger 18 can be bypassed in some cases. Cooled vapor stream 30 flows to expander 34 where it is expanded to a pressure slightly above the operating pressure of NGL recovery column 50. Alternatively, the vapor in stream 30 may by-pass expander 34 through control valve 34a. Stream 32 from the expander discharge possesses a temperature and pressure of at about -84°F and about 610 psia and is fed to NGL recovery column 50 right below the upper rectifying section. It should be noted that, in cases where the feed gas pressure is close to the operating pressure of NGL recovery column 50, cooled stream 16 leaving exchanger block 300 can be directly fed to NGL recovery column. As indicated by dashed line 38 expansion device 26 is not

required. Similarly, cooled feed gas stream 14a can be delivered directly to NGL recovery column 50 either alone or after being combined with the cooled gas in line 38. Alternatively, cooled feed gas stream 14a can be fed to separator 22 and the resulting gas stream fed to the NGL recovery column or combined with cooled stream 16 and fed to the NGL recovery column.

The NGL recovery column operated at about 600 psia is a conventional distillation column containing a plurality of mass contacting devices, trays or packings, or some combinations of the above. It is typically equipped with one or more liquid draw trays in the lower section of the column to permit heat inputs to the column for stripping volatile components off from the bottom liquid product . Liquid collected in draw tray 50a is withdrawn via stream 46a and heated by countercurrent heat exchanger in side reboiler 48 prior to re-introduction to the NGL recovery column. Similarly, liquid condensed in the lower draw tray 50b is withdrawn via stream 46b, partially vaporized in gas/liquid exchanger 18, and re-introduced to the NGL recovery column.

Bottom liquid stream 44 also referred to herein as the first liquid stream, containing substantially all of the heavier hydrocarbons is withdrawn from NGL recovery column 50 and directly introduced into the middle portion of a second distillation column, i.e., NGL purifying column 70. Stream 44 is separated in NGL purifying column 70 operated at a pressure of about 440 psia into an NGL product stream 64 comprising mainly propane, propylene and heavier hydrocarbons, i.e., the C_{3+} hydrocarbons, and a vapor comprising mainly ethane and lighter hydrocarbons. The purity of the NGL product stream is controlled by external heat input via bottom reboiler 62. The NGL product stream exits column 70 at about 235°F and is cooled to about 120°F via exchanger 66 for delivery as product stream 68.

Vapor stream 52 is withdrawn from the top of NGL purifying column 70 through an overhead line. Vapor phase stream 52 is cooled to partial condensation in side reboiler 48 prior to return to reflux drum 54 at a temperature of about -9°F. The heat carried by vapor stream 52 is effectively transferred to the NGL recovery column as external heat input. This is accomplished by a unique thermal integration between the overhead condenser and the side reboiler for NGL purifying column 70. The partially condensed stream is separated in reflux drum 54 into vapor and liquid phases. The liquid

accumulated in reflux drum 54 is withdrawn via line 58 where it is pumped via reflux pump 60 for re-introduction to the NGL purifying column as top reflux.

Vapor stream 72 withdrawn from reflux drum 54 comprises mainly methane and ethane which were present in feed stream 44. The concentration of propane and higher components in vapor stream 72 is very low. Vapor stream 72 is directed into exchanger block 300 for recovering available refrigeration. In cases where the available refrigeration is limited or not needed, stream 72 can bypass exchanger block 300 and simplify the exchanger block design. A combined stream formed by warmed stream 72a and optionally, excess flashed vapor stream 102, if any, is compressed to a higher pressure at about 635 psia in compressor 96 prior to being cooled in after-cooler 98. The cooled, combined vapor stream 104 returns to exchanger block 300 where it is further cooled to substantial condensation using refrigeration employed in the liquefaction process thereby producing stream 42. The substantially condensed stream 42 is introduced to NGL recovery column 50 as top reflux. Stream 42, characterized by a very low content of C_{3+} hydrocarbons, reduces the equilibrium loss of C_{3+} hydrocarbons in the overhead vapor to a minimum. The introduction of a lean reflux stream in the present invention permits the column to be operated at a relatively high pressure, e.g., about 600 psia in this example, while maintaining high recovery of C_{3+} hydrocarbon liquids.

Lighter and more volatile gases primarily rich in methane are withdrawn from the top of NGL recovery column 50 via overhead stream 40. This stream may be compressed in compressor 36 which preferably utilizes work extracted from expander 34 before delivery to exchanger block 300. Alternately, the overhead stream 40 can be directly sent to exchanger block 300 without further compression as shown with dashed line 40a in cases where the expander 34 is not available or the work extracted from the expander is used for other services. In the illustrative example, the overhead stream 40 is directly introduced to exchanger block 300. It should be noted that lean reflux stream 42 may also be vapor stream 72 from NGL purifying column 70 or a portion of flashed vapor stream 80 alone, or any combination of these two streams.

The methane-rich overhead stream from NGL recovery column 50 at about –112°F and about 600 psia is totally liquefied and in most cases substantially sub-cooled in exchanger block 300 utilizing appropriate refrigeration from refrigeration block 200.

Sub-cooled LNG at an elevated pressure is delivered via stream 74 from exchanger block 300 to expansion block 400 where it is expanded to near atmospheric pressure through one or more expansion steps. Expansion block 400 illustrates a typical arrangement with one expansion step. Sub-cooled LNG is expanded through expansion means 76 to about 25 psia causing partial vaporization in discharge line 78. A hydraulic turbine optionally can be employed as an expansion means to reduce flashing as a result of pressure reduction. Any flashed vapor in expanded LNG stream 78 is separated from the liquid portion in separator 82. The liquid portion withdrawn from separator 82 comprises LNG product stream 84 for delivery to storage. Although illustrated as a single expansion step, the expansion provided in expansion block 400 can also be carried out in multiple stages. For instance, a liquefaction process utilizing cascaded refrigeration, either closed or open cycle, typically involves 3 or 4 expansion stages. Although not shown in Fig. 1, it should also be noted that additional flashed vapor will be generated when the final LNG product 84 is delivered to the LNG tank for storage due mainly to further pressure let-down and heat gain in the cryogenic storage tank at the ambient pressure. This flashed vapor stream is typically compressed and combined with the flashed vapor stream 80 via the use of a boil-off gas compressor.

Flashed vapor stream 80 from separator 82, primarily comprising methane, nitrogen and other lighter components, enters exchanger block 300 for recovery of available cold refrigeration. The warmed, flashed vapor stream 86 leaves exchanger block 300 at about 66°F and is compressed to a pressure of about 425 psia via methane compressor 88. The compressed vapor stream is then cooled to about 100°F through after-cooler 90 prior to being used as fuel gas via stream 92. It should be noted that, depending upon the pressures of the expansion steps and the final fuel gas supply pressure, more than one compression and cooling step may be required. Any portion of excess flashed vapor stream 102 may be combined with the warm vapor stream 72a for recycle to the top of NGL recovery column 50 as reflux after being further compressed and cooled to substantial condensation.

<u>Open Cycle Cascaded Refrigeration Process Employing Figure 1 Embodiment</u>

As mentioned previously, mechanical refrigeration cycles mostly in closed circuit are often employed and dictate the detailed cooling and liquefaction steps in the LNG

process. Fig. 2 illustrates in a non-limiting manner an open cycle cascaded refrigeration process in conjunction with the embodiment of the present invention illustrated in Fig. 1. In this illustration, three refrigerant loops or cycles are employed (e.g. propane, ethylene and methane). Each refrigeration cycle employs an effective number of refrigeration stages, such effective number being nominally two and preferably 2 to 4. In the embodiment depicted in Figure 2, the preferred number of stages in the first, second and third cycles, that being 3, 2 and 3, respectively are employed. The preferred refrigerant for the first refrigeration cycle is propane. The preferred refrigerant for the second refrigeration cycle is ethylene or ethane, most preferably ethylene. The preferred refrigerant for the third refrigeration cycle is preferably methane, but may contain small concentrations of nitrogen and other light hydrocarbons.

Referring to Fig. 2, the configuration and operation of the first refrigeration cycle, having the highest boiling point among the three, such as propane, is described. Propane refrigerant stream 202a withdrawn from the propane surge drum 220 at about 100°F and approximately 190 psia is directed to a pressure reduction device, e.g., expansion valve 204a, and expanded to a lower pressure, thereby flashing a portion of the propane refrigerant stream and lowering its temperature. The resulting two-phase stream is directed into the high-stage propane chiller 310a as a coolant in indirect heat exchange with the following:

a) feed gas, such as stream 12,
b) the second refrigerant stream 240, such as ethylene, and the
c) Combined vapor stream 104.

via conduits 302a, 208a, and 206a respectively in chiller 310a.

The flashed propane vapor stream 210a from the chiller 310a is fed to the high-stage inlet port of the propane compressor 212 through the high-stage suction line. Liquid propane stream 202b from chiller 310a is directed to a pressure reduction valve 204b to further reduce its pressure, thereby flashing an additional portion of propane refrigerant stream and further lowering its temperature. The resulting two-phase stream is directed into the inter-stage propane chiller 310b as a coolant in indirect heat exchange with the cooled feed gas split from conduit 302a and the second refrigerant vapor stream from conduit 206a via conduits 302b and 206b, respectively.

The flashed propane vapor stream 210b from the chiller 310b is fed to the inter-stage inlet port of propane compressor 212 through the inter-stage suction line. Liquid propane stream 202c from chiller 310b is further directed to a pressure reduction valve 204c to reduce its pressure, thereby flashing another portion of propane refrigerant stream and lowering its temperature still further. The resultant two-phase stream is directed into low-stage propane chiller 310c as a coolant in indirect heat exchange with the cooled feed gas split from conduit 302b and the second refrigerant stream from conduit 206b via conduits 302c and 206c, respectively.

The flashed propane vapor stream 210c from chiller 310c is fed through the low-stage suction line to the low-stage inlet port of the propane compressor 212. Propane vapor is compressed in a three-stage propane compressor 212 typically driven by a gas turbine. Although they may be separate units tandem driven by a single driver, the three stages preferably form a single unit. Compressed propane vapor stream 214 flows through condenser 216 where it is liquefied at about 100°F and about 190 psia in the illustrated system, prior to being returned via line 218 to propane surge drum 220. Exemplary temperatures for the three propane refrigeration levels, respectively, in the illustrated example are about 62°F, about 12°F, and about –25°F.

Similar to the first refrigeration, the second refrigeration, cycle, that being illustrated as the ethylene refrigeration cycle in Fig. 2 is a closed two-stage system. In addition, an economizer 246 is incorporated in the ethylene refrigeration. As illustrated in Fig. 2, the ethylene refrigerant stream 240a exits the low-stage propane chiller 310c, in most cases, totally condensed and is directed to ethylene surge drum 244 at about –21°F and approximately 300 psia. Ethylene refrigerant stream 222a withdrawn from ethylene surge drum 244 is directed to the ethylene economizer 246 where it is sub-cooled prior to a pressure reduction device such as an expansion valve 224a. The sub-cooled ethylene is expanded to a lower pressure across expansion valve 224a, thereby flashing a portion of ethylene refrigerant stream and lowering its temperature. The amount of ethylene flashed in this pressure reduction step is reduced as a result of sub-cooling prior to expansion via the use of ethylene economizer 246. The resulting two-phase stream is directed into the high-stage ethylene chiller 330a as a coolant in indirect heat exchange with the main feed gas split stream 12a from the low-stage propane chiller 310c and cooled vapor stream

104c from the methane economizer 360, via conduit 324a and 326a respectively. Depending on the effective temperature required for stream 16, a portion of cooled feed gas stream 12a might bypass the ethylene refrigeration loop as stream 12b.

The flashed ethylene vapor stream 230a from the chiller 330a is fed to the ethylene economizer 246 to provide refrigeration for sub-cooling ethylene refrigerant as previously described thereby producing a warmed high stage ethylene gas stream 232a which is fed through high-stage suction line to the high-stage inlet port of ethylene compressor 234. Liquid ethylene stream 222b from the chiller 330a is directed to the ethylene economizer 246. It is then directed to a pressure reduction valve 224b to further reduce its pressure and lowering its temperature further. The resulting two-phase stream from expansion device 224b is introduced the low-stage ethylene chiller 330b as a coolant in indirect heat exchange with methane-rich overhead vapor stream 40a from NGL recovery column 50 as depicted in Fig. 1 and cooled vapor stream from conduit 326b via conduits 324c and 326c respectively. In most cases, both streams leave the low-stage ethylene chiller 330b totally liquefied as liquid streams 40b and 42 respectively.

The flashed ethylene vapor stream 230b from low-stage chiller 330b returns to the ethylene economizer to provide refrigeration for ethylene sub-cooling thereby producing a warmed low stage ethylene gas stream 232b which is fed to the low-stage inlet port of ethylene compressor 234 through low-stage suction line. Ethylene vapor is compressed in the illustrative two-stage compressor 234 typically driven by a gas turbine. Before being re-introduced into the next stage compression, the compressed ethylene vapor stream is cooled to partially reject the heat of compression to the atmosphere via after-cooler 238b. The compressed ethylene stream 236 produced by compressor 234 is cooled in after-cooler 238a. After the preceding steps of compression and cooling, the refrigerant vapor stream 240 returns to the propane chillers for further cooling and condensation as previously described, thereby completing the ethylene cycle. Exemplary temperatures for two ethylene refrigeration levels, respectively, in the illustrated example are about -70°F, and about –126°F.

The combined vapor stream 104 leaves the high-stage propane chiller 310a via conduit 208a as stream 104a and is directed to the methane economizer 360 for further cooling. Preferably, a portion of stream 104a is withdrawn from the middle of the

methane economizer 360 at about –35°F via stream 104c. Stream 104c is subsequently condensed 42 via ethylene chillers 330a and 330b and used as the top lean reflux stream. The remaining portion leaves the economizer 360 at a colder temperature of about –110°F via stream 104b. Stream 104b is preferably combined with stream 40a from the NGL recovery column 50 and then condensed in the chiller 330b as liquefied LNG stream 40b, thereby simplifying the chiller design, although it can be condensed in a separate conduit of chiller 330b and thereafter combined with liquefied stream 40a to form stream 40b.

The liquefied LNG stream 40b from the low-stage ethylene chiller 330b at an elevated pressure is further cooled in the methane economizer 360. The sub-cooled LNG stream 74 exits the methane economizer 360 and is directed to the expansion block 400 as shown in Fig. 2. Inside the expansion block 400, LNG stream 74 undergoes a series of pressure reduction stages, preferably corresponding in number to the number of open methane cycle refrigeration stages, to near atmospheric pressure. A non-limiting three-stage expansion as illustrated in Fig. 2. LNG stream 74 is first directed to an expansion valve 76a and expanded to a lower pressure, resulting in flashing a portion of the pressurized LNG stream and lowering its temperature. The resultant two-phase stream is fed to the high stage flash drum 82a wherein any flashed vapor is removed from the top as high stage flashed vapor stream 80a. As previously noted, liquid expanders (i.e. hydraulic turbines) may be employed in place of any of the expansion valves.

Flashed vapor stream 80a from flash drum 82a is fed to the methane economizer 360 to provide refrigeration and is then compressed by the expander compressor 36 utilizing the work extracted from expander 34 when available. Compressed high stage flash vapor stream 86a is thereafter introduced through high-stage suction line to the high-stage inlet port of methane compressor 88. LNG stream 74b is removed from flash drum 82a and is directed to sub-cooler 410. It is then expanded through a pressure reduction valve 76b to further reduce its pressure and lower its temperature. The resulting two-phase stream from expansion device 76b is introduced into the inter-stage flash drum 82b wherein any flashed vapor is removed from the top as inter-stage flashed vapor stream 80b.

Likewise, the inter-stage flashed vapor stream 80b from flash drum 82b is fed to sub-cooler 410 and then methane economizer 360 to recover available cold refrigeration.

After recovering available refrigeration, the flashed vapor stream is warmed to near ambient temperature thereby producing a warmed inter-stage flashed vapor stream 86b which is sent through the inter-stage suction line to the inter-stage inlet port of methane compressor 88. LNG stream 74c is removed from flash drum 82b and preferably undergoes the third pressure expansion through expansion valve 76c directly thereby lowering its temperature further, although it can be re-introduced to sub-cooler 410 prior to such expansion for further cooling. The resulting two-phase stream from expansion valve 76c is introduced to the low-stage flash drum 82c wherein any flashed vapor is removed from the top as the low-stage flashed vapor stream 80c. Final LNG product stream 84 is removed from the bottom of flash drum 82c and delivered to storage.

The low-stage flashed vapor stream 80c from flash drum 82c is fed to sub-cooler 410 and subsequently to the methane economizer 360 to recover its available cold refrigeration thereby producing a warmed low stage flashed vapor stream 86c which is subsequently introduced through inter-stage suction line to the low-stage inlet port of methane compressor 88. The warmed flashed vapor streams are compressed via a two or three-stage compressor 88 depending on the requirement of fuel gas supply pressure. After-coolers such as 90a, 90b, or 90c are often provided after each compression stage to partially reject the heat of compression to the atmosphere. After the final stage of compression and cooling, a portion of the flashed vapor stream is used as plant fuel gas 92. Stream 102 comprised of any excess flashed vapor is further compressed and cooled via compressor 96 and after-cooler 98 respectively. The cooled vapor stream 104 returns to exchanger block 300 where it is further cooled to substantial condensation using propane and ethylene refrigeration as described earlier. It should be noted that, in most open-cycle cascaded refrigeration applications, compressor 96 is typically considered as the final compression stage, and is part of compressor 88 which preferably consists of three stages.

Depending on its pressure level, the vapor stream 72 withdrawn from the reflux drum 54 shown in Fig. 1 can be combined either with excess flashed vapor stream 102 or with high stage flash vapor stream 86a as shown via the dashed line. Alternately, vapor stream 72, although not shown in Fig. 2, may be introduced to the methane economizer 360 by combining with stream 80a for recovering its cold refrigeration in cases where it

temperature is relatively cold. Such steam may also provide refrigeration via a separate conduit methane economizer 360.

Table 1 summarizes the results of a numerical simulation of the embodiment of the invention illustrated above for a target recovery of C_{3+} hydrocarbons exceeding 98%. As indicated in Table 1, recovery of 99.2% of propane and 100% of all C_4+ hydrocarbons can be achieved via this embodiment.

Table 1

Stream	Temp	Press.	Components Flow (ibmol/hr)					
	F	psia	methane	ethane	propane	butanes	C5+	total
10	100	1015	47325	2319	1423	1054	579	52700
32	-83	610	43567	1704	709	313	62	46355
40	-112	600	63844	1695	11	0	0	65550
68	120	440	0	28	1411	1054	579	3072
72	-9	440	1257	1218	2	0	0	2477
84	-246	24.7	42630	2286	12	0	0	44928
92	100	415	4695	5	0	0	0	4700

Liquid product recovery:

% Propane recovery	99.2
% Butanes recovery	100.0
% C5+ recovery	100.0

While the integration of NGL recovery into an LNG facility in accord with the present invention has been effectively demonstrated for high C_{3+} recovery, the aforementioned methods can also be easily modified by adjusting the operating parameters either for enhanced ethane recovery or for the recovery of C_{5+} components alone in cases where recovery of lighter NGL components is not desirable. To achieve high ethane recovery, the temperature profile inside NGL recovery block 100 typically needs to be reduced, the reflux stream needs to be leaner and the reflux flow should be increased. Table 2 summarizes the numerical simulation results of the operation of the system illustrated in Fig. 1 in conjunction with the open cycle cascaded refrigeration process of Fig. 2 under ethane recovery conditions using the same feed gas composition and conditions as used in Table 1. As illustrated, ethane recovery above 83% is achieved using the process of the present invention illustrated in Fig. 1, but optimized for enhanced

ethane recovery.

Table 2

Stream	Temp	Press.	Components Flow (ibmol/hr)					
	F	psia	methane	ethane	propane	butanes	C5+	total
10	100	1015	47325	2319	1423	1054	579	52700
32	-110	600	28981	950	395	201	58	30585
40	-112	590	66523	350	1	0	0	66874
68	120	440	39	1927	1422	1054	579	5021
72	-104	440	1686	119	0	0	0	1805
84	-247	24.7	42587	391	1	0	0	42979
92	-100	415	4695	5	0	0	0	4700

Liquid product recovery:	
% Ethane recovery	83.1
% Propane recovery	99.9
% Butanes recovery	100.0
% C5+ recovery	100.0

Propane Pre-Cooled Mixed Refrigerant Process Employing Fig. 1 Embodiment

As described earlier, there are numerous processes available in the art for liquefying natural gas which differ mainly in the refrigeration cycle used. Integration of the present invention with any LNG process, independent of the type of refrigeration cycle or cycles used, for high recovery of NGL is yet another objective of the present invention.

In addition to the open cycle cascaded refrigeration process represented in Fig. 2, other refrigeration cycles for liquefying natural gas known to the art can also be integrated with the present invention. Alternative arrangements of exchanger block 300 and refrigeration block 200 utilizing other refrigeration cycles commonly employed in the LNG process are discussed below and in the following sections. The systems described herein merely provide exemplary illustrations of the use of the present invention with other refrigeration processes for liquefying inlet gas and should not be considered as limiting the methods of the present invention to the specific refrigeration processes described.

Another example representing a typical arrangement of exchanger block 300 and

refrigeration block 200 utilizing the propane pre-cooled mixed refrigeration cycle in conjunction with the embodiment of the present invention of Fig. 1 is described below with a schematic shown in Fig. 3. Recovery of C_{3+} hydrocarbons in excess of 95% from a dry gas feed of about 400 MMSCFD is desired. Again, the dry feed gas has been pre-treated as necessary to remove undesirable components, and contains about 90 mol% methane, 4.9 mol% ethane, 2.3 mol% propane, 2.0 mol% butanes, 0.7 mol% C5 and heavier components, and the remaining non-hydrocarbon components. The application and operation of the present invention shown in Fig. 1 in this example is essentially the same as the previous example and is briefly described here. The differences mainly reside on the exchanger blocks 200, 300, and 400 and concern the integration of the propane pre-cooled mixed refrigeration process. In addition, methane-rich vapor stream 40 from the top of NGL recovery column 50 will be compressed in compressor 36 utilizing work extracted from expander 34 before being directed to exchanger block 300.

Referring to Fig. 1, the dry feed gas enters the facility through inlet stream 10 and is first cooled to about –43°F via two paths similar to the previous example prior to entering separator 22 for separation of condensed liquid, if any, as stream 24. Liquid stream 24 is expanded through expansion device 26 and preheated in gas/liquid exchanger 18 prior to introduction into NGL recovery column 50 for further fractionation. Cooled vapor stream 30 is expanded at about 610 psia via expander 34 and then fed as a cooled gas or condensate (i.e., two phase) stream 32 to NGL recovery column 50 right below the upper rectifying section.

The NGL recovery column, a conventional distillation column containing a plurality of mass transfer devices, is operated at about 600 psia. Within the NGL recovery column, stream 32 is fractionated into a bottom liquid stream 44 containing substantially all of the heavier hydrocarbons and an overhead stream 40 comprising lighter and more volatile gases primarily rich in methane. Liquid stream 44 is further introduced into the middle portion of the NGL purifying column 70 where ethane and lighter components are stripping off the bottom NGL product 64. The NGL product stream exits column 70 at about 230°F and is cooled to about 120°F via exchanger 66 for delivery to product stream 68. The vapor stream 72 from the NGL purifying system comprises mainly methane and ethane, with essentially free of propane and higher

components utilizing a thermal integration of side reboiler 48 as previously described.

After recovering available refrigeration in exchanger block 300, the warm vapor stream 72a is combined with a portion of excess flashed vapor stream 102, if any and compressed via compressor 96 to a pressure sufficient to return the compressed stream when liquefied to the top of NGL recovery column 50 as the top reflux. Following compression, the stream is cooled in after-cooler 98. The resulting cooled vapor stream 104 returns to exchanger block 300 where it is further cooled to substantial condensation and produced as stream 42. The substantially condensed stream 42, characterized by a very low content of C_{3+} hydrocarbons, is introduced to the NGL recovery column 50 as top reflux to achieve high recovery of C_{3+} hydrocarbons.

The overhead stream 40 from the top of NGL recovery column 50 at about –101°F and about 600 psia is first compressed in compressor 36 utilizing work extracted from expander 34 prior to entering the exchanger block 300. It is totally liquefied and in most cases deeply sub-cooled in exchanger block 300 utilizing appropriate refrigeration from refrigeration block 200. Sub-cooled LNG at an elevated pressure is delivered via stream 74 from exchanger block 300 to expansion block 400 where it is expanded to near atmospheric pressure through typically one expansion step to about 20 psia causing partial vaporization and production of a two phase LNG-bearing stream 78. A hydraulic turbine optionally can be employed as an expansion means to reduce flashing as a result of pressure reduction. Any flashed vapor in expanded LNG stream 78 is separated from the liquid portion in separator 82. The LNG product stream 84 withdrawn from the separator 82 is then delivered to storage tank.

Flashed vapor stream 80 from separator 82, primarily comprising methane, nitrogen and other lighter components, enters exchanger block 300 for the recovery of available cold refrigeration. Warmed, flashed vapor stream 86 leaves exchanger block 300 at about 65°F and is compressed in one or more stages to a fuel gas at a pressure of about 420 psia via fuel gas compressor 88. The compressed vapor stream is then cooled to about 100°F through after-cooler 90 prior to being used as fuel gas stream 92. Any portion of excess flashed vapor stream 102 may be combined with the warm vapor stream 72a for recycle to the top of NGL recovery column 50 as reflux stream 42.

Fig. 3 illustrates in more detail a typical arrangement of exchanger block 300 and

refrigeration block 200 utilizing the propane pre-cooled mixed refrigeration cycle in conjunction with the embodiment of the present invention illustrated in Fig. 1. Referring to Fig. 3, an illustrative three-stage propane refrigeration cycle in closed circuit is configured essentially the same as that in Fig. 2 and operates in a similar manner accordingly. The three-stage propane refrigeration cycle provides high level cooling for a) feed gas, such as stream 12 from Fig. 1, and b) the mixed refrigerant vapor stream 502 from refrigerant compressor after-cooler 524b. Exemplary temperatures for the three propane refrigeration levels, respectively, in the illustrated example are about 60°F, about 10°F, and about –30°F.

Partially condensed, mixed refrigerant leaving conduit 206c via stream 502a is introduced into separator 504. The condensed portion is removed from the bottom of separator 504 as stream 506 at about –26 °F and about 640 psia. Condensed refrigerant stream 506 is further cooled in exchanger 320 via conduit 506a to about –188°F. Sub-cooled refrigerant stream 514 is directed to a pressure reduction means, e.g., expansion valve 516, to lower the pressure thereby producing expanded refrigerant stream 518 which returns to exchanger 320 as a coolant.

Non-condensed vapor refrigerant stream 508 from separator 504 is divided into two portions, those portions being streams 510 and 512. Main portion stream 510 flows through exchanger 320 where it is liquefied and, optionally, sub-cooled to about –235°F via conduit 510a. Remaining vapor portion stream 512 passes through exchanger 340 where it is liquefied and sub-cooled thereby producing stream 524 via indirect heat exchange with flashed vapor stream 80 from expansion block 400 in Fig. 1. Other streams entering exchanger 340 include combined vapor stream 104 from after-cooler 98 and overhead vapor stream 72 from reflux drum 54 as depicted in Fig. 1. Inside exchanger 340, streams 72 and 80 are warmed before exiting exchanger 340 at about 65°F as streams 72a and 86, respectively. On the other hand, stream 104 is cooled and exits exchanger 340 as stream 104a at about –26°F.

Sub-cooled refrigerant stream 524 exiting from exchanger 340 at about –245°F is combined with the other sub-cooled refrigerant stream from conduit 510a and thereafter directed to a pressure reduction means, e.g., expansion valve 526, to a lower pressure before being returned as stream 528 to exchanger 320 as a coolant. After providing the

coldest portion of refrigeration, expanded refrigerant stream 528 is combined with the other expanded refrigerant stream 518 in exchanger 320 where it flows through said exchanger via conduit 528a. The combined refrigerant stream provides the refrigeration necessary for cooling the following streams in exchanger 320:

- feed gas stream 12a from low-stage propane chiller 310c;
- methane-rich vapor stream 40a from NGL recovery column 50 in Fig. 1; and
- cooled vapor stream 104a from exchanger 340,

via conduits 322a, 322b, and 322c, respectively, thereby producing respective streams 16, 74 and 42.

Although not illustrated in Fig. 3, a hydraulic turbine may be used as a pressure reduction means for the sub-cooled refrigerant in place of expansion valves 516 or 526 illustrated therein. During the expansion process, work can also be extracted by a hydraulic turbine, thereby lowering the refrigerant temperature further and enhancing liquefaction efficiency and overall plant throughput.

After providing refrigeration, the combined mixed refrigerant exits exchanger 320 as warmed and vaporized stream 520 at about –30°F and about 50 psia. Warmed refrigerant stream 520 is then compressed and cooled. An exemplary compression and cooling configuration is illustrated in Fig. 3 with two stages. Stream 520 is first compressed to about 250 psia via low stage refrigerant compressor 522a and then cooled to about 100°F via low stage refrigerant after-cooler 524a. The cooled and compressed stream is further compressed and cooled to form stream 502 at about 655 psia and about 100°F via high stage refrigerant compressor 522b and after-cooler 524b, thus completing the closed circuit.

Table 3 summarizes the results of a numerical simulation of the embodiment of the invention illustrated above for a target recovery of C_{3+} hydrocarbons exceeding 98%. As indicated in Table 3, recovery of 98.4% of propane and 100% of all C_4+ hydrocarbons can be achieved via this embodiment utilizing another refrigeration process, namely the propane pre-cooled mixed refrigerant process.

Table 3

Stream	Temp	Press.	Components Flow (lbmol/hr)						
	°F	psia	methane	ethane	propane	butanes	C5+	Non-hydrocarbons	total
10	100	1000	39527	2152	1010	878	307	44	43918
32	-84	608	36523	1629	544	299	51	42	39088
40	-101	600	41877	2132	16	0	0	61	44086
68	120	440	0	20	994	878	307	0	2199
72	-16	440	1495	1118	10	0	0	1	2624
84	-251	20	35805	2131	16	0	0	16	37968
92	100	415	3722	1	0	0	0	27	3750

Liquid product recovery:

% Propane recovery	98.4
% Butanes recovery	100.0
% C5+ recovery	100.0

Single, Mixed Refrigerant Process Employing Figs. 1 and 5 Embodiments

In addition to the open cycle cascaded refrigeration process represented in Fig. 2 and the propane pre-cooled mixed refrigerant process represented in Fig. 3, other mechanical refrigeration cycles for liquefying natural gas known to the art can also be integrated with the present invention. One such process being the single, mixed refrigerant process. The single, mixed refrigerant process includes heavier hydrocarbons, e.g., butanes and pentanes, in the multi-component, mixed, refrigeration stream and in so doing, eliminates the need for a propane pre-cooled refrigeration cycle. Fig. 4 illustrates the embodiment of the present invention as depicted in Fig. 1 further including the single, mixed refrigerate process via exchanger block 300 and refrigeration block 200.

Referring to Fig. 4, mixed refrigerant stream 502 exits the final compression and cooling stage from high stage after-cooler 524b partially condensed as it contains some heavier components in the mixture. The partially condensed refrigerant stream 502 is introduced into separator 504 from which the condensed portion is removed from the bottom of the separator as stream 506. The non-condensed vapor refrigerant stream 508 from separator 504 is divided into two portions corresponding to streams 510 and 512, respectively. The condensed refrigerant stream 506 is pumped via high stage refrigerant pump 538 as stream 536 for combination with the main vapor portion stream 510. The combined stream flows through exchanger 320 where it is liquefied and in most cases sub-cooled in conduit 510a. The remaining vapor portion stream 512 passes through exchanger 340 where it is also liquefied and sub-cooled in indirect heat exchange with the flashed vapor stream 80 from expansion block 400 and the overhead vapor stream 72 from reflux drum 54 as illustrated in Fig. 1 thereby producing a liquefied and subcooled stream 524. Streams 72 and 80 are warmed inside exchanger 340 before exiting as streams 72a and 86, respectively. Sub-cooled refrigerant stream 524 from exchanger 340 is combined with the other sub-cooled refrigerant stream exiting from conduit 510a in exchanger 320. The combined stream is then directed to a pressure reduction means, e.g., expansion valve 526, and expanded to a lower pressure for return to exchanger 320 as coolant stream 528. The combined refrigerant stream provides via conduit 528a the refrigeration necessary for cooling the following:

- feed gas stream 12;

- methane-rich vapor stream 40a from NGL recovery column 50 in Fig. 1; and
- combined vapor stream 104 from after-cooler 98 as depicted in Fig. 1.

via conduits 322a, 322b, and 322c, respectively, thereby producing respective streams 16, 74 and 42.

Although not illustrated in Fig. 4, a hydraulic turbine may be used as a pressure reduction means for the sub-cooled refrigerant stream in place of expansion valve 526. During the expansion process, work may also be extracted by a hydraulic turbine, thereby lowering the refrigerant temperature further. Consequently, liquefaction efficiency and overall plant throughput are further enhanced. Alternatively, instead of being combined, liquid refrigerant stream 536 and vapor refrigerant stream 510 can enter exchanger 320 in separate paths and be expanded at different pressure levels.

After providing refrigeration, the mixed refrigerant stream exiting exchanger 320 has been warmed and vaporized to form stream 520. Warmed refrigerant stream 520 is then compressed and cooled again. Fig. 4 illustrates an exemplary two-stage system for performing this compression and cooling. Stream 520 is first compressed via low stage refrigerant compressor 522a and then cooled via low stage refrigerant after-cooler 524a thereby producing cooled refrigerant stream 526 which is directed to the high stage suction scrubber 528 for removal of any condensed refrigerant. The non-condensed refrigerant withdrawn from scrubber 528 is subsequently compressed to final pressure via high stage refrigerant compressor 522b thereby producing a compressed refrigerant stream 532. The condensed refrigerant separated in scrubber 528 is pumped via refrigerant pump 530 and the resulting stream 534 combined with compressed refrigerant stream 532. The combine stream then flows through after-cooler 524b, thereby producing stream 502, thus completing the closed circuit.

Recovery efficiency is further improved in another embodiment of the present invention wherein a second reflux is introduced to the NGL recovery column. Fig. 5 represents a schematic embodiment illustrating this improvement to further enhance recovery efficiency. The system illustrated in Fig. 5 is essentially identical to that in Fig. 1 and operates in a similar manner with the exception of the differences detailed below. The same reference numerals have been used to represent the same system components in each figure.

With reference to Fig. 5, a small slipstream 106, about 12.5% in the illustrative example, from the pre-cooled feed gas stream 12a in exchanger block 300 is taken for further cooling to substantial condensation by utilizing appropriate refrigeration. In some cases, slipstream 106 may be sub-cooled depending upon the refrigeration level available for the liquefaction process. Sub-cooled stream 108 exits exchanger block 300 at about -170°F and about 975 psia. Stream 108 is thereafter introduced into the middle of the rectification section of NGL recovery column 50 as a middle reflux after pressure reduction to the column pressure via expansion valve 110.

The introduction of a middle reflux provides a bulk rectification effect while substantially retaining the NGL components for recovery in the downward liquid flow, thereby minimizing the recoverable NGL components in the up-flow vapor stream. Any residual NGL components in the upward vapor can all be substantially recovered by the leaner top reflux. As a result, the same NGL recovery can be achieved with a significantly reduced top reflux flow. LNG stream 74 from exchanger block 300 can be further sub-cooled to reduce flashed vapor stream 80 from expansion block 400 to the minimum required for the fuel gas requirements. Consequently, excess flashed vapor stream 102 can be eliminated, leading to a substantial reduction in the compression horsepower required for fuel gas compressor 88. Thus, overall recovery efficiency can be significantly enhanced.

The feed gas is pre-cooled to a temperature where most of the components having high freezing points are condensed and separated in the liquid phase in separator 22. The vapor stream withdrawn from separator 22 comprises very few of these high freezing point components, thus eliminating the concerns of freezing. In some cases, the feed gas contains much heavier components, e.g., hexane, C_{6+} alkanes and aromatics, which tend to freeze when cooled to cryogenic temperatures, in particular temperatures below –120°F. For those cases, slipstream 30a taken from the vapor portion withdrawn from the top of separator 22 as illustrated with a dashed line in Fig. 5 can be used as stream 106 or as an alternative stream 12 can be cooled to such extent that two phases exist, the resulting stream separated via a separator into gas and liquid streams and the gas stream employed as stream 106 and the liquid stream optionally fed directly or in combination with another stream to the distillation column 50. In the cascade process, such additional

cooling is readily available in one of the refrigeration stages in the second refrigeration cycle.

The results of a numerical simulation based on the embodiment illustrated in Fig. 5 and the same inlet gas and conditions employed in the example based on Fig. 1 and shown in Table 3 are presented in Table 4. Table 4 summarizes the overall performance of a LNG process incorporating a second reflux stream as described with reference to Fig. 5. As indicated in Table 4, propane recovery is improved to 99.1%.

Table 4

Stream	Temp	Press	Components Flow (lbmol/hr)						
	°F	psia	methane	ethane	propane	butanes	C5+	non-hydrocarbons	total
10	70	1000	39527	2152	1010	878	307	44	43918
32	-83	608	33702	1512	508	281	48	39	36090
40	-100	600	39532	2132	9	0	0	44	41717
68	120	440	0	20	1001	878	307	0	2206
72	-4	440	1382	1475	11	0	0	1	2869
84	-251	20	35805	2131	9	0	0	16	37961
92	100	415	3722	1	0	0	0	27	3750

Liquid product recovery:

% Propane recovery	99.1
% Butanes recovery	100.0
% C5+ recovery	100.0

Although not illustrated in the preceding Example, the second reflux may be fed to the top of the NGL recovery column alone or in combination with the other top reflux stream 42. While this will simplify the design of the upper rectification section, the recovery efficiency may be reduced slightly.

Figure 6 Embodiment Employing Pressurized LNG as Reflux.

In yet another embodiment of the present invention, illustrated in Fig. 6, high recovery of NGL components can also be achieved by recycling a portion of the sub-cooled LNG at elevated pressure as the top reflux to NGL recovery column 50. The LNG stream, again containing a very low content of NGL components, serves as an enhanced lean reflux to achieve high recovery efficiency in this embodiment. The system illustrated in Fig. 6 is essentially the same as that illustrated in Fig. 1 and operates in a similar manner. The difference resides in the source of the top reflux to the NGL recovery column 50.

Referring to Fig. 6, stream 40 withdrawn from the overhead of NGL recovery column 50 is totally liquefied and, in most cases, sub-cooled in exchanger block 300 via conduit 112. Appropriate refrigeration from refrigeration block 200 is used for this liquefaction and sub-cooling. Prior to introduction into exchanger block 300, methane-rich overhead stream 40 may be raised in pressure via expander/compressor 36 utilizing work extracted from expander 34 when available as previously described. At least a portion of the sub-cooled LNG stream is re-introduced to the top of NGL recovery column 50 as reflux via line 42. In some cases where the expander/compressor 36 is not present, a cryogenic pump 116 may be used to return this reflux to the top of the recovery column as illustrated via the dashed line.

The main portion of the sub-cooled LNG stream is further cooled before exiting the exchanger block 300 as stream 74 at a much colder temperature about –242 °F. Accordingly, the flow rate of flashed vapor stream 80 from expansion block 400 is greatly reduced before being directed to the fuel gas system after recovering refrigeration and compression. Additional heat input is provided to the lower stripping section of recovery column 50 to further strip lighter components off bottom liquid stream 44. This also leads to a reduction in overhead vapor stream 72 from reflux drum 54 associated with NGL purifying column 70. This overhead vapor stream 72 is also directed to the fuel gas

system. Further, a second reflux such as that disclosed in Fig. 5 may be incorporated to further improve recovery efficiency as illustrated previously.

When recovery of lighter NGL components is not desirable, the aforementioned method can also be effectively applied for the recovery of C_{5+} components alone as those heavy components tend to freeze out and need to be removed prior to final liquefaction. To achieve this, the temperature profile inside the NGL recovery block 100 will typically be warmer and the reflux stream should be reduced. In addition, the NGL recovery block 100 can be further simplified by eliminating the side and bottom reboilers, and others depicted in Fig. 7 as an alternate embodiment of the present invention.

<u>Figure 7 Embodiment Employing Feed Gas as Stripping Gas</u>

The effectiveness of introducing the enhanced reflux for the removal of C5 and heavier components from a LNG-bearing gas stream can be demonstrated by the following example. This example is based on the inventive scheme of Fig. 7 in conjunction with the open cycle cascaded refrigeration process of Fig. 2. The simulation employed a dry feed gas at 650 psia and 100°F and the composition set forth in Table 1.

With reference to Fig. 7, dry feed gas stream 10 is first divided into stream 12 and 14. The main stream 12 is cooled in the exchanger block 300 to about –70°F utilizing the propane and ethylene refrigeration of the cascaded process shown in Fig. 2 as the coolant. The cooled feed gas stream 16 from the exchanger block 300 is introduced to the NGL recovery column 50 right below the upper rectifying section. The separator 22, expander 34 and compressor 36 are not required in this example because the feed gas pressure is close to the operating pressure of the NGL recovery column 50.

The NGL recovery column 50 contains two sections, trays or packings, preferably packings in both sections. To simplify its design, the typical one or more liquid draw trays for facilitating heat inputs to the lower section of the column are eliminated. The smaller portion, stream 14, instead of being cooled such as via exchanger 18 in Fig. 1, is directly sent to the bottom of the NGL recovery column 50 as a stripping gas to reduce the content of lighter NGL components in the bottom liquid stream to the maximum extent. Although not illustrated in Fig. 7, stream 14 can be cooled prior to introduction into the bottom of the column via indirect heat exchange with at least a portion of the first liquid stream (i.e. the bottom liquid stream) which is produced from the bottom of said column.

In the later mode, additional cooling via the first liquid stream is possible by first flashing the first liquid stream to a pressure slightly above the operating pressure of the NGL purification column.

The bottom liquid stream 44 containing substantially all of the C5 and heavier hydrocarbons is withdrawn from NGL recovery column 50. It is expanded to about 235 psia and used as a cooling media for reflux exchanger 48a prior to being introduced into the middle portion of NGL purifying column 70 operated at about 220 psia. Within column 70, all C4 and lighter components are removed from the top reflux system as a vapor stream 72, and a stabilized condensate with a Reid vapor pressure (RVP) of less than 12 psia is produced from the bottom. The RVP of stabilized condensate is controlled by external heat input via bottom reboiler 62. The operation of column 70 is adjusted such that the concentration of C5 and higher components in the vapor stream 72 is maintained very low. The NGL product stream exits column 70 at about 325°F and is cooled to about 120°F via exchanger 66 for delivery to product stream 68.

The vapor phase stream 72 withdrawn from reflux drum 54 at about 113°F will bypass the exchanger block 300 and directly combined with the warm flashed vapor stream 86a from flash drum 82a via the dashed line shown in Fig. 2. The combined stream is compressed to a higher pressure at about 645 psia and cooled in after-cooler 98. In a typical arrangement demonstrated in Fig. 2, it is subsequently cooled via propane chiller 310 and methane economizer 360 with a slipstream withdrawn from the middle of the economizer 360 as stream 104c and the balance of said stream further cooled in the main methane economizer and produced as stream 104b. Stream 104c is further cooled to substantial condensation via ethylene chillers 330a and 330b. The substantially condensed stream 42 is introduced to the NGL recovery column 50 as top reflux. Reflux stream 42, very lean in C_{5+} hydrocarbons, effectively reduces the equilibrium loss of C_{5+} hydrocarbons in the overhead vapor stream to a minimum.

The LNG-bearing gases primarily rich in methane are withdrawn from the top of NGL recovery column 50 via overhead stream 40a. This stream is directly sent to the exchanger block 300 where it is combined with stream 104b for liquefaction at an elevated pressure via the ethylene chiller 330b and thereafter undergoes a typical three-stage expansion as detailed in Fig. 2 to produce near ambient LNG for storage.

Table 5 summarizes the results of a numerical simulation for the above-cited embodiment for the removal of C_5 and heavier. As indicated, the vapor stream 40a from the column 50 contains less than 0.1 ppmv of aromatics, including benzene, cyclohexane, and toluene and none for C7 and heavier components. This is compared to about 3.6 ppmv of benzene represented by the vapor portion of stream 32 feeding to the column 50, when no rectification of the present invention is employed in the top section of the NGL recovery column 50. In the case of the present invention, any entrained liquid will have a composition represented by reflux stream 42. In this example such stream will contain less than 0.3 ppmv of benzene, thereby significantly reducing the freezing concern incurred by the phenomena of liquid entrainment.

Table 5

Stream	Temp	Press.	Composition, ppmv						
	F	psia	C5	nC6	Benz.	Cyclo-C6	Toluene	nC7	C8+
10	100	650	7500	1000	600	600	400	500	400
32-vap	-72	625	191	5.6	3.6	3.08	0.7	0.78	0.14
32-liq	-72	625	52269	7089	4252	4254	2845	3557	2848
40a	-77	620	79.9	0.072	0.06	0.037	0.001	0.000	0.000
42	-119	640	2517	0.44	0.28	0.072	0.000	0.001	0.000
68	120	200	594338	111103	66652	66674	44456	55570	44456
84	-245	24.7	2135	0.44	0.29	0.098	0.002	0.002	0.000

For a further demonstration generated via numerical simulation, a representative composition profile of designated C6 and heavier components inside the NGL recovery column is listed in Table 6. It is shown that the compositions of the designated components are greatly reduced as the vapor traveling upwards and in contact with the top lean reflux for the top three stages where the rectification section is located.

Table 6

			Composition, ppmv					
			Benzene		Cyclo-hexane		N-heptane	
Stage	Temp F	Press psia	vapor	liquid	vapor	liquid	vapor	liquid
Top	-76.9	620	0.06	60.7	0.037	44.4	0.000	3.57
2	-71.6	620.7	0.58	596	0.42	511	0.032	130
3	-70.9	621.4	3.54	4134	3.03	4134	0.76	3442
4	-61.6	622.1	4.58	4300	3.92	4299	1.03	3579
5	-48.5	622.9	6.62	4446	5.68	4445	1.57	3699
6	-32.4	623.6	10.4	4566	8.92	4563	2.62	3794
7	-14.0	624.3	17.4	4778	14.8	4771	4.65	3957
Bottom	11.3	625	39.3	6574	33.6	6574	11.8	5479

Figure 8 Embodiment Employing Enhanced Stripping Gas Generation

Another aspect of the present invention which offers a significant economic advantage is the cooling of the feed gas by countercurrent heat exchange with a refrigerant stream comprising a portion of bottom liquid stream 44 or liquid withdrawn from the lower portion of NGL recovery column 50. Illustrated in Fig.8 is an alternative arrangement of a cryogenic NGL recovery process incorporating this modification. A side liquid stream 120 is withdrawn from the lower portion of NGL recovery column 50. This liquid is directed to pressure reduction valve 122 to reduce its pressure and thereby flash a portion of the liquid refrigerant. Expanded liquid refrigerant stream 124 at a lower temperature flows through gas/liquid exchanger 18 to provide additional refrigeration to cool inlet gas portion 14. Stream 126 carries the partially vaporized liquid exiting exchanger 18 to suction knockout drum 128 where it is separated into vapor and liquid portions. The vapor portion withdrawn from the top of knockout drum 128 through line 130 is directed to recycle compressor 132 where it is compressed to a pressure slightly higher than that of the NGL recovery column. The compressed gas from compressor 132 is cooled in cooler 134 prior to re-introduction to NGL recovery column 50 as a stripping gas.

The liquid portion accumulated at the bottom of knockout drum 128 is withdrawn via line 136. This liquid portion, comprising primarily propane and heavier hydrocarbons, is pumped by recycle pump 138 to NGL purifying column 70 for further fractionation.

The introduction of stripping gas (sometimes referred to as enrichment gas) supplements the heat requirements in NGL recovery column 50 for stripping volatile components from the bottom liquid stream 44. It also enhances the relative volatility of the key components and, accordingly, improves the separation efficiency of the column, particularly when the column is operated at a relatively high pressure as in the NGL recovery column illustrated here.

One should note that the feature set forth above for enhanced cooling of the feed gas can also be applicable to the embodiment set forth in Figure 7 wherein a portion of the feed gas is employed as the stripping gas. That portion of the feed gas to be employed as a stripping gas is first cooled prior to introduction into the bottom of the column via

indirect heat exchange with two phase stream 126. Warmed two-phase 126 can then be fed directly to the NGL purification column 70 as stream 44.

Figure 9 Embodiment Employing Simplified NGL Purification System

Yet another embodiment of the present invention is illustrated in Fig. 9. The NGL purifying system can be simplified by eliminating the overhead reflux system, resulting in savings on capital investment. Referring to Fig. 9 where only NGL recovery block 100 is illustrated, bottom liquid stream 44 from NGL recovery column 50 is split into two portions. One portion 44b is directly introduced into the middle portion of the NGL purifying column 70, as illustrated in Figs. 1, 4, 5 and 6. The other portion 44a is directed to reflux exchanger 48 where it is substantially sub-cooled. The sub-cooled liquid 44c from reflux exchanger 48 is introduced to the top of NGL purifying column 70 as reflux to reduce the equilibrium loss of heavy hydrocarbons in vapor stream 72. An exemplary source for the cold stream for reflux exchanger 48 is a liquid side-draw from NGL recovery column 50 as illustrated in Fig. 9. Consequently, the reflux drum and pumps can be eliminated.

Conclusion

In the foregoing specification, the invention has been described with reference to specific embodiments thereof, and has been demonstrated as effective in providing methods for maximizing the recovery of NGL components from a natural gas stream within an LNG facility. The examples demonstrated herein were generated via numerical simulation of the embodiment of interest at the stated conditions using Hyprotech's Process Simulation HYSIM, with Prop. Pkg. PR/LK. "HYSIM ver. 2.2 was used for all examples employing cascaded refrigeration thus providing the results presented in Tables 1, 2, 5 and 6. HYSIM ver. 2.7. was used for the propane precooled mixed refrigerant and single, mixed refrigerant examples thus providing the results presented in Tables 3 and 4". However, it will be evident to those skilled in the art that various modifications and changes can be made thereto without departing from the true spirit or scope of the invention. Accordingly, the specification is to be regarded in an illustrative rather than a restrictive sense. There may be other ways of configuring and/or operating the integration system of the present invention differently or in association with different liquefaction processes from those explicitly described herein which nevertheless fall within the true

spirit and scope of the invention. For example, it is anticipated that by routing certain streams differently or by adjusting operating parameters, different optimizations and efficiencies may be obtained which would nevertheless not cause the system to fall outside of the scope of the present invention. Additionally, it must also be noted that, while the foregoing embodiments have been described in considerable detail for the purpose of disclosure, many variations, e.g., the arrangement and number of heat exchangers and compression stages, may be made therein. Therefore, the invention in its broadest embodiment is not restricted to the preferred embodiments described and illustrated herein but rather covers all modifications which may fall within the scope of the appended claims.

CLAIMS

1. A process for recovering the relatively less volatile components from a methane-rich gas feed under pressure to produce an NGL product while rejecting the relatively more volatile components which are subsequently liquefied to produce LNG, comprising the steps of:

cooling at least a portion of a gas feed in one or more heat exchangers by means of a mechanical refrigeration cycle;

introducing said gas feed into an NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components and a first liquid stream primarily comprising relatively less volatile components;

introducing said first liquid stream into an NGL purifying column at one or more feed stages to produce an NGL product stream comprising desirable less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column;

cooling said second gas stream and thereafter introducing said cooled, second gas stream to the top portion of said NGL recovery column as an overhead reflux to enhance recovery of desirable less volatile components; and

liquefying said first gas stream to produce a pressurized LNG stream.

2. The process of claim 1, wherein the step of cooling and introducing said gas feed into the NGL recovery column further comprises:

separating said cooled gas feed into a cooled vapor portion and a cooled liquid portion comprising condensed components, if any;

dividing said cooled vapor portion into a first vapor portion and a second vapor portion;

further cooling said first vapor portion to substantial condensation and thereafter introducing said substantially condensed first vapor portion into an upper portion of said NGL recovery column as a middle reflux; and

introducing the remaining portion of said cooled gas feed comprising said second vapor portion and said cooled liquid portion into said NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively

more volatile components rich in methane and a first liquid stream primarily comprising relatively less volatile components.

3. The process of claim 1 or 2, wherein said mechanical refrigeration cycle includes a refrigerant selected from the group consisting of single-component refrigerants and multi-component refrigerants.

4. The process of claim 1 or 2, wherein a refrigeration stream is withdrawn from said NGL recovery column to provide at least a portion of the refrigeration in said first cooling step.

5. The process of claim 4, wherein said refrigeration stream is partially vaporized as a result of said cooling and further comprising separating said partially vaporized refrigeration stream into a first gas phase which is re-introduced into said NGL recovery column and a first liquid phase.

6. The process of claim 1 or 2, wherein said second gas stream is cooled to partial condensation with the condensed liquid being introduced to a top portion of said NGL purifying column as an overhead reflux and the remaining vapor being introduced to a top portion of said NGL recovery column as an overhead reflux after further cooling.

7. The process of claim 6, wherein said second gas stream is cooled by a refrigeration stream withdrawn from said NGL recovery column.

8. The process of claim 1 or 2, further comprising expanding said pressurized LNG stream in one or more expanding stages to produce an LNG stream suitable for storage and producing said overhead reflux from a portion of the flashed vapor generated in one or more of said expanding stages.

9. The process of claim 1 or 2, further comprising compressing said second gas stream prior to cooling.

10. The process of claim 1 or 2, further comprising utilizing at least one mechanical refrigeration cycle in the cooling of said second gas stream and in the liquefying of said first gas stream.

11. A process for recovering the relatively less volatile components from a methane-rich gas feed to produce an NGL product while rejecting the relatively more volatile components which are subsequently liquefied to produce LNG, comprising the steps of:

cooling at least a portion of a gas feed in one or more heat exchangers by means of a mechanical refrigeration cycle;

further cooling a portion of said cooled gas feed to substantial condensation and thereafter introducing said substantially condensed gas feed into the top of an NGL recovery column as an overhead reflux;

introducing the remaining portion of said cooled gas feed into said NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components rich in methane and a first liquid stream primarily comprising relatively less volatile components;

introducing said first liquid stream into an NGL purifying column at one or more feed stages to produce an NGL product stream comprising desirable less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column; and

liquefying said first gas stream to produce a pressurized LNG stream.

12. The process of claim 11, wherein the step of cooling and introducing said gas feed into the NGL recovery column further comprises:

separating said cooled gas feed into a cooled vapor portion and a cooled liquid portion comprising condensed components, if any;

dividing said cooled vapor portion into a first vapor portion and a second vapor portion;

further cooling said first vapor portion to substantial condensation and thereafter introducing said substantially condensed first vapor portion into an upper portion of said NGL recovery column as an overhead reflux; and

introducing the remaining portion of said cooled gas feed comprising said second vapor portion and said cooled liquid portion into said NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components rich in methane and a first liquid stream primarily comprising relatively less volatile components.

13. The process of claim 11 or 12, wherein a refrigeration stream is withdrawn from said NGL recovery column to provide at least a portion of the refrigeration in said first cooling step.

14. The process of claim 13, wherein said refrigeration stream is partially vaporized as a result of said cooling and further comprising separating said partially vaporized refrigeration stream into a first gas phase which is re-introduced into said NGL recovery column and a first liquid phase.

15. The process of claim 11, wherein said mechanical refrigeration cycle includes a refrigerant selected from the group consisting of single-component refrigerants and multi-component refrigerants.

16. A process for recovering the relatively less volatile components from a methane-rich gas feed to produce an NGL product while rejecting the relatively more volatile components which are subsequently liquefied to produce LNG, comprising the steps of:

cooling at least a portion of a gas feed in one or more heat exchangers by means of mechanical refrigeration cycle;

introducing said cooled gas feed into an NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components and a first liquid stream primarily comprising relatively less volatile components;

introducing said first liquid stream into an NGL purifying column at one or more feed stages to produce an NGL product comprising desirable less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column;

liquefying said first gas stream to produce a pressurized LNG stream; and

introducing at least a portion of said pressurized LNG stream to the top of said NGL recovery column as an overhead reflux to enhance recovery of relatively less volatile components.

17. The process of claim 16, wherein the step of cooling and introducing said gas feed into the NGL recovery column further comprises:

separating said cooled gas feed into a cooled vapor portion and a cooled liquid portion comprising condensed components, if any;

dividing said cooled vapor portion into a first vapor portion and a second vapor portion;

further cooling said first vapor portion to substantial condensation and thereafter

introducing said substantially condensed first vapor portion into an upper portion of said NGL recovery column as a middle reflux; and

introducing the remaining portion of said cooled gas feed comprising said second vapor portion and said cooled liquid portion into said NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components rich in methane and a first liquid stream primarily comprising relatively less volatile components.

18. A process for recovering the relatively less volatile components from a methane-rich gas feed under pressure to produce an NGL product while rejecting the relatively more volatile components which are subsequently liquefied to produce LNG, comprising the steps of:

cooling at least a portion of a gas feed in one or more heat exchangers by means of a mechanical refrigeration cycle;

introducing said cooled gas feed into an NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components and a first liquid stream primarily comprising relatively less volatile components;

introducing said first stream into an NGL purifying column at one or more feed stages to produce an NGL product comprising desirable less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column;

liquefying said first gas stream to produce a pressurized LNG stream;

expanding said pressurized LNG stream in one or more stages to a lower pressure to produce an LNG stream suitable for storage and at least one flashed vapor stream; and compressing and cooling at least a portion of said flashed vapor stream to substantial condensation and thereafter introducing said substantially condensed, flashed vapor stream to a top portion of said NGL recovery column as an overhead reflux to enhance recovery of desirable less volatile components.

19. The process of claim 18, wherein said mechanical refrigeration cycle includes a refrigerant selected from the group consisting of single-component refrigerants and multi-component refrigerants.

20. The process of claim 18, wherein a refrigeration stream is withdrawn from said NGL recovery column to provide at least a portion of the refrigeration in said first cooling step.

21. The process of claim 20, wherein said refrigeration stream is partially vaporized as a result of said cooling and further comprising separating said partially vaporized refrigeration stream into a first gas phase which is re-introduced into said NGL recovery column and a first liquid phase.

22. The process of claim 18, wherein said second gas stream is cooled to partial condensation with the condensed liquid being introduced to a top portion of said NGL purifying column as an overhead reflux and the remaining vapor being introduced to a top portion of said NGL recovery column as an overhead reflux after further cooling.

23. The process of claim 22, wherein said second gas stream is cooled by a refrigeration stream withdrawn from said NGL recovery column.

24. Apparatus for recovering the relatively less volatile components from a methane-rich gas feed under pressure to produce an NGL product while rejecting the relatively more volatile components which are subsequently liquefied to produce LNG, comprising:

a first heat exchanger for cooling at least a portion of a gas feed by means of a mechanical refrigeration cycle;

an NGL recovery column for receiving said cooled gas feed at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components and a first liquid stream primarily comprising relatively less volatile components;

an NGL purifying column for receiving said first liquid stream at one or more feed stages to produce an NGL product stream comprising desirable less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column;

a second heat exchanger for cooling said second gas stream;

means for introducing said cooled, second gas stream to the top portion of said NGL recovery column as an overhead reflux to enhance recovery of desirable less volatile components; and

means for liquefying said first gas stream to produce a pressurized LNG stream.

25. The apparatus of claim 24, further comprising:

a first separator for separating said cooled gas feed into a cooled vapor portion and a cooled liquid portion comprising condensed components, if any;

means for dividing said cooled vapor portion into a first vapor portion and a second vapor portion;

a third heat exchanger for further cooling said first vapor portion to substantial condensation;

means for introducing said substantially condensed, cooled, first vapor portion into said NGL recovery column as a middle reflux; and

means for introducing said second vapor portion and said cooled liquid portion into said NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components rich in methane and a first liquid stream primarily comprising relatively less volatile components.

26. The apparatus of claim 24,wherein said mechanical refrigeration cycle includes a refrigerant selected from the group consisting of single-component refrigerants and multi-component refrigerants.

27. The apparatus of claim 24,further comprising means for expanding said pressurized NGL stream in one or more stages to a lower pressure to produce an NGL stream suitable for storage and means for directing at least a portion of the flashed vapor generated in one or more expanding stages to said NGL recovery column as said overhead reflux.

28. The apparatus of claim 24, further comprising a compressor for compressing said second gas stream prior to cooling to substantial condensation.

29. Apparatus for recovering the relatively less volatile components from a methane-rich gas feed to produce an NGL product while rejecting the relatively more volatile components which are subsequently liquefied to produce LNG, comprising:

a first heat exchanger for cooling at least a portion of a gas feed by means of a mechanical refrigeration cycle;

means for further cooling a portion of said cooled gas feed to substantial condensation;

an NGL recovery column;

means for introducing said condensed gas feed into the top of said NGL recovery column as an overhead reflux;

means for introducing the remaining portion of said cooled gas feed into said NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components rich in methane and a first liquid stream primarily comprising relatively less volatile components;

an NGL purifying column for receiving said first liquid stream at one or more feed stages to produce an NGL product stream comprising desirable less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column; and

means for liquefying said first gas stream to produce a pressurized LNG stream.

30. The apparatus of claim 29, further comprising:

a first separator for separating said cooled gas feed into a cooled vapor portion and a cooled liquid portion comprising condensed components, if any;

means for dividing said cooled vapor portion into a first vapor portion and a second vapor portion;

means for further cooling said first vapor portion to substantial condensation; means for introducing said substantially condensed, cooled, first vapor portion into said NGL recovery column as an overhead reflux; and

means for introducing said second vapor portion and said cooled liquid portion into said NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components rich in methane and a first liquid stream primarily comprising relatively less volatile components.

31. Apparatus for recovering the relatively less volatile components from a methane-rich gas feed to produce an NGL product while rejecting the relatively more volatile components which are subsequently liquefied to produce LNG, comprising:

one or more heat exchangers for cooling at least a portion of a gas feed by means of mechanical refrigeration cycle;

an NGL recovery column for receiving said cooled gas feed at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components and a first liquid stream primarily comprising relatively less volatile

components;

an NGL purifying column for receiving said first liquid stream at one or more feed stages to produce an NGL product comprising desirable less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column;

means for liquefying said first gas stream to produce a pressurized LNG stream; and

means for introducing at least a portion of said pressurized LNG stream to the top of said NGL recovery column as an overhead reflux to enhance recovery of relatively less volatile components.

32. The apparatus of claim 31, further comprising:

a first separator for separating said cooled gas feed into a cooled vapor portion and a cooled liquid portion comprising condensed components, if any;

means for dividing said cooled vapor portion into a first vapor portion and a second vapor portion;

means for further cooling said first vapor portion to substantial condensation; means for introducing said substantially condensed, cooled, first vapor portion into said NGL recovery column as a middle reflux; and

means for introducing said second vapor portion and said cooled liquid portion into said NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components rich in methane and a first liquid stream primarily comprising relatively less volatile components.

33. Apparatus for recovering the relatively less volatile components from a methane-rich gas feed under pressure to produce an NGL product while rejecting the relatively more volatile components which are subsequently liquefied to produce LNG, comprising:

a first heat exchanger for cooling at least a portion of a gas feed by means of a mechanical refrigeration cycle;

an NGL recovery column for receiving said cooled gas feed at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components and a first liquid stream primarily comprising relatively less volatile components;

an NGL purifying column for receiving said first liquid stream at one or more feed stages to produce an NGL product stream comprising desirable less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column;

means for liquefying said first gas stream to produce a pressurized LNG stream;

means for expanding said pressurized LNG stream in one or more stages to a lower pressure to produce an LNG stream suitable for storage and at least one flashed vapor stream;

means for compressing and cooling at least a portion of said flashed vapor stream to substantial condensation; and

means for introducing said substantially condensed, flashed vapor stream to a top portion of said NGL recovery column as an overhead reflux to enhance recovery of desirable less volatile components.

34. The apparatus of claim 33, wherein said mechanical refrigeration cycle includes a refrigerant selected from the group consisting of single-component refrigerants and multi-component refrigerants.

35. In a process for liquefying a pressurized methane-rich gas stream via a cascaded refrigeration process employing a closed two- or three-stage propane refrigeration cycle, a closed two- or three-stage ethane or ethylene refrigeration cycle and an open methane refrigeration cycle employing two or more flash stages and wherein said methane-rich gas stream contains appreciable concentrations of C_{2+} hydrocarbons, the improvement comprising:

(a) cooling at least a portion of said methane-rich gas stream via indirect heat exchange with one or more propane refrigerant streams from the propane refrigeration cycle and at least one ethane or ethylene refrigerant stream from the ethane or ethylene refrigeration cycle thereby producing a cooled methane-rich stream;

(b) introducing said cooled methane-rich stream into an NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components and a first liquid stream primarily comprising relatively less volatile components;

(c) introducing said first liquid stream into an NGL purifying column at one or

more feed stages to produce an NGL product stream comprising less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column;

(d) compressing said second gas stream to a pressure at least as great as that existing in the NGL recovery column;

(e) cooling said compressed second gas stream via indirect heat exchange with at least one refrigerant stream from the propane refrigeration cycle and at least one refrigerant stream from the ethane or ethylene refrigeration cycle thereby condensing said stream and thereafter introducing said condensed stream to the top portion of said NGL recovery column as an overhead reflux to enhance recovery of less volatile components; and

(f) condensing and subcooling said first gas stream via indirect heat exchange with at least one refrigerant stream from the ethane or ethylene refrigeration cycle and via indirect heat exchange with one or more flashed vapor streams from the open methane cycle thereby producing a pressurized and subcooled LNG stream.

36. A process according to claim 35, wherein said cooling of the compressed second gas stream further comprises cooling said stream via indirect heat exchange with one or more flashed vapor streams from the open methane cycle.

37. A process according to claim 36, wherein a three-stage propane refrigeration cycle is employed and said methane-rich gas stream is contacted via indirect heat exchange means with a propane refrigerant stream from each pressure reduction stage in the propane refrigeration cycle, an ethane or ethylene refrigerant stream from at least the first pressure reduction stage of the ethane or ethylene cycle and said indirect heat exchange with one or more flash vapor streams is after indirect heat exchange with said refrigerant streams from the propane refrigeration cycle but before indirect heat exchange with an ethane or ethylene refrigerant stream from at least the first pressure reduction stage of the ethane or ethylene refrigeration cycle.

38. A process according to claim 37, wherein said at least one refrigerant stream from the ethane or ethylene refrigeration cycle is the refrigerant stream from the first pressure reduction stage in said refrigeration cycle.

39. A process according to claim 35, wherein cooling step (a) further comprises

recovering at least one liquid stream from the stream undergoing cooling and feeding said liquid stream either directly or in combination with another stream to the NGL recovery column.

40. A process of claim 35, wherein the step of cooling and introducing said methane-rich gas stream into the NGL recovery column further comprises:

separating in the cooling step of (a) said methane-rich gas stream having undergone initial cooling into a cooled vapor portion stream and a cooled liquid portion;

dividing said cooled vapor portion stream into a first vapor portion stream and a second vapor portion stream;

further cooling in the cooling step of (a) said first vapor portion stream to at least substantial condensation and thereafter introducing said substantially condensed first vapor portion stream into an upper portion of said NGL recovery column as a middle reflux; and

introducing the remaining portion of said cooled methane-rich stream comprising said second vapor portion stream and said cooled liquid portion stream as separate or combined streams or only said second vapor portion stream into said NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components rich in methane and a first liquid stream primarily comprising relatively less volatile components.

41. In a process for liquefying a pressurized methane-rich gas stream via a cascaded refrigeration process employing a closed three-stage propane refrigeration cycle, a closed two-stage ethylene refrigeration cycle and an open methane refrigeration cycle employing three flash stages and three stages of compression and wherein said methane-rich gas stream contains appreciable concentrations of C_{2+} hydrocarbons, the improvement comprising:

(a) cooling at least a portion of said methane-rich gas stream via indirect heat exchange with a refrigerant stream from each pressure reduction stage in the propane refrigeration cycle and the first pressure reduction stage in the ethylene refrigeration cycle thereby producing a cooled methane-rich stream;

(b) introducing said cooled methane-rich stream into an NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising

relatively more volatile components and a first liquid stream primarily comprising relatively less volatile components;

(c) introducing said first liquid stream into an NGL purifying column at one or more feed stages to produce an NGL product stream comprising less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column;

(d) compressing said second gas stream to a pressure at least as great as that existing in the NGL recovery column;

(e) cooling said compressed second gas stream via indirect heat exchange with (I) refrigerant from the first pressure reduction stage in the propane refrigeration cycle, (ii) flashed vapor streams from the first, second and third stages of the open methane cycle and (iii) refrigerant from the first and second pressure reduction stages in the ethylene refrigeration cycle thereby condensing the majority of said stream and thereafter introducing said condensed stream to the top portion of said NGL recovery column as an overhead reflux to enhance recovery of less volatile components; and

(f) condensing and subcooling said first gas stream via indirect heat exchange with the refrigerant stream from the second pressure reduction stage in the ethylene refrigeration cycle and flashed vapor streams from the first, second and third stages of the open methane cycle thereby producing a pressurized and subcooled LNG stream.

42. In a process for liquefying a pressurized methane-rich gas stream via a cascaded refrigeration process employing a closed two- or three-stage propane refrigeration cycle, a closed two- or three-stage ethane or ethylene refrigeration cycle and an open methane refrigeration cycle employing two or more flash stages and wherein said methane-rich gas stream contains appreciable concentrations of C2+ hydrocarbons, the improvement comprising:

(a) cooling at least a portion of said methane-rich gas stream via indirect heat exchange with one or more propane refrigerant streams from the propane refrigeration cycle and at least one ethane or ethylene refrigerant stream from the ethane or ethylene refrigeration cycle thereby producing a cooled methane-rich stream;

(b) further cooling at least a portion of said cooled methane-rich stream to at least substantial condensation via indirect heat exchange with at least one ethane or ethylene

refrigerant stream from the ethane or ethylene refrigeration cycle or at least one flashed vapor stream from the open methane cycle thereby producing a substantially condensed stream;

(c) introducing said substantially condensed gas stream into the top of an NGL recovery column as an overhead reflux stream;

(d) introducing the remaining portion of said cooled methane-rich stream into said NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components rich in methane and a first liquid stream primarily comprising relatively less volatile components; and

(e) condensing and subcooling said first gas stream via indirect heat exchange with at least one refrigerant stream from the ethane or ethylene refrigeration cycle and one or more flashed vapor streams from the open methane cycle thereby producing a pressurized and subcooled LNG stream.

43. A process according to claim 42, additionally comprising the step of:

(f) introducing said first liquid stream into an NGL purifying column at one or more feed stages to produce an NGL product stream comprising less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column.

44. A process according to claim 42, wherein the step of cooling and introducing said methane-rich gas stream into the NGL recovery column further comprises:

separating in the cooling step of (a) said methane-rich gas stream having undergone initial cooling into a cooled vapor portion stream and a cooled liquid portion stream;

dividing said cooled vapor portion stream into a first vapor portion stream and a second vapor portion stream;

further cooling said first vapor portion stream to at least substantial condensation as set forth in step (b) and introducing said stream into the upper portion of said NGL recovery column as an overhead reflux; and

introducing the remaining portion of said cooled methane-rich stream comprising said second vapor portion stream and said cooled liquid portion stream as separate or combined streams or only said second vapor portion stream into said NGL recovery

column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components rich in methane and a first liquid stream primarily comprising relatively less volatile components.

45. A process according to claim 42, wherein said cooling of step (b) further comprising indirect heat exchange of said portion of cooled methane-rich stream with one or more flashed vapor streams from the open methane refrigeration.

46. A process according to claim 42, wherein cooling step (a) further comprises removing at least one liquid stream from the stream undergoing cooling and feeding said liquid stream either directly or in combination with another stream to the NGL recovery column.

47. In a process for liquefying a pressurized methane-rich gas stream via a cascaded refrigeration process employing a closed three-stage propane refrigeration cycle, a closed two-stage ethylene refrigeration cycle and an open methane refrigeration cycle employing three flash stages and three stages of compression and wherein said methane-rich gas stream contains appreciable concentrations of C_{2+} hydrocarbons, the improvement comprising:

(a) cooling at least a portion of said methane-rich gas stream via indirect heat exchange with a refrigerant stream from each pressure reduction stage in the propane refrigeration cycle and at least the ethylene refrigerant stream from the first pressure reduction stage in the ethylene refrigeration cycle thereby producing a cooled methane-rich stream;

(b) further cooling a portion of said cooled methane-rich stream to at least substantial condensation via indirect heat exchange with at least the ethylene refrigerant stream from the second pressure reduction stage in the ethylene refrigeration cycle thereby substantially condensing said stream and introducing said substantially condensed gas stream into the top of an NGL recovery column as an overhead reflux stream;

(c) introducing the remaining portion of said cooled methane-rich stream into said NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components rich in methane and a first liquid stream primarily comprising relatively less volatile components;

(d) introducing said first liquid stream into an NGL purifying column at one or

more feed stages to produce an NGL product stream comprising desirable less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column; and

(e) condensing and subcooling said first gas stream via indirect heat exchange with the refrigerant stream from the second pressure reduction stage in the ethylene refrigeration cycle and flashed vapor streams from the first, second and third stages of the open methane cycle thereby producing a pressurized and subcooled LNG stream.

48. In a process for liquefying a pressurized methane-rich gas stream via a cascaded refrigeration process employing a closed two- or three-stage propane refrigeration cycle, a closed two- or three-stage ethane or ethylene refrigeration cycle and an open methane refrigeration cycle employing two or more flash stages and wherein said methane-rich gas stream contains appreciable concentrations of C_{2+} hydrocarbons, the improvement comprising:

(a) cooling at least a portion of said methane-rich gas stream via indirect heat exchange with a refrigerant stream from each pressure reduction stage in the propane refrigeration cycle and at least the ethylene refrigerant stream from the first pressure reduction stage in the ethylene refrigeration cycle thereby producing a cooled methane-rich stream;

(b) introducing said cooled methane-rich stream into an NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components and a first liquid stream primarily comprising relatively less volatile components;

(c) cooling said first gas stream via indirect heat exchange with at least one refrigerant stream from the ethane or ethylene refrigeration cycle to produce a pressurized LNG stream; and

(d) introducing at least a portion of said pressurized LNG stream to the top of said NGL recovery column as an overhead reflux to enhance recovery of relatively less volatile components.

49. A process according to claim 48, additionally comprising the step of:

(e) introducing said first liquid stream into an NGL purifying column at one or more feed stages to produce an NGL product stream comprising desirable less volatile

components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column.

50. A process according to claim 48, further comprising:

(e) further cooling the pressurized LNG stream of step (c) via indirect heat exchange with one or more flashed vapor streams from the open methane cycle prior to step (d).

51. A process according to claim 48, wherein the step of cooling and introducing said methane-rich gas stream into the NGL recovery column further comprising:

separating in the cooling step of (a) said methane-rich gas stream having undergone initial cooling into a cooled vapor portion stream and a cooled liquid portion stream comprising condensed components, if any;

dividing said cooled vapor portion stream into a first vapor portion stream and a second vapor portion stream;

further cooling said first vapor portion stream to at least substantial condensation as set forth in step (b) and introducing said stream into the upper portion of said NGL recovery column as a middle reflux; and

introducing the remaining portion of said cooled methane-rich stream comprising said second vapor portion stream and said cooled liquid portion stream as separate or combined streams or only said second vapor portion stream into said NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components rich in methane and a first liquid stream primarily comprising relatively less volatile components.

52. A process according to claim 48, wherein cooling step (a) further comprises removing at least one liquid stream from the stream undergoing cooling and feeding said liquid stream either directly or in combination with another stream to the NGL recovery column.

53. In a process for liquefying a pressurized methane-rich gas stream via a cascaded refrigeration process employing a closed two- or three-stage propane refrigeration cycle, a closed two- or three-stage ethane or ethylene refrigeration cycle and an open methane refrigeration cycle employing two or more flash stages and wherein said methane-rich gas stream contains appreciable concentrations of C_{2+} hydrocarbons, the improvement

comprising:

(a) cooling at least a portion of said methane-rich gas stream via indirect heat exchange with a refrigerant stream from each pressure reduction stage in the propane refrigeration cycle and at least the ethylene refrigerant stream from the first pressure reduction stage in the ethylene refrigeration cycle thereby producing a cooled methane-rich stream;

(b) introducing said cooled methane-rich stream into an NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components and a first liquid stream primarily comprising relatively less volatile components;

(c) condensing and subcooling said first gas stream via indirect heat exchange with at least one refrigerant stream from the ethane or ethylene refrigeration cycle and one or more flashed vapor streams from the open methane cycle thereby producing a pressurized and subcooled LNG stream;

(d) expanding said pressurized and subcooled LNG stream in two or more stages to a lower pressure to produce an LNG stream suitable for storage and at least two flashed vapor streams;

(e) compressing at least a portion of said flashed vapor streams to a pressure greater than the pressure existing in the NGL recovery column; and

(f) cooling at least a portion of said compressed flashed vapor stream via indirect heat exchange with at least one refrigerant stream from the propane refrigeration cycle and at least one refrigerant stream from the ethane or ethylene refrigeration cycle thereby condensing said stream and thereafter introducing said condensed stream to the top portion of said NGL recovery column as an overhead reflux stream to enhance recovery of less volatile components.

54. A process according to claim 53, wherein the cooling step of (g) further comprising cooling said compressed gas stream via indirect heat exchange with one or more flashed vapor streams.

55. A process according to claim 53, additionally comprising the step of:

(f) introducing said first liquid stream into an NGL purifying column at one or more feed stages to produce an NGL product stream comprising desirable less volatile

components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column.

56. A process according to claim 55, further comprising:

(h) combining at least a portion of the second gas stream and at least a portion of one of said flashed vapor streams prior to compression of said combined stream via step (f).

57. A process according to claim 53, wherein cooling step (a) further comprises recovering at least one liquid stream from the stream undergoing cooling and feeding said liquid stream either directly or in combination with another stream to the NGL recovery column.

58. A process of claim 53, wherein the step of cooling and introducing said methane-rich gas stream into the NGL recovery column further comprising:

separating in the cooling step of (a) said methane-rich gas stream having undergone initial cooling into a cooled vapor portion stream and a cooled liquid portion stream comprising condensed components;

dividing said cooled vapor portion stream into a first vapor portion stream and a second vapor portion stream;

further cooling said first vapor portion stream to at least substantial condensation as set forth in step (b) and introducing said stream into the upper portion of said NGL recovery column as a middle reflux; and

introducing the remaining portion of said cooled methane-rich stream comprising said second vapor portion stream and said cooled liquid portion stream as separate or combined streams or only said second vapor portion stream into said NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components rich in methane and a first liquid stream primarily comprising relatively less volatile components.

59. In a process for liquefying a pressurized methane-rich gas stream via a cascaded refrigeration process employing a closed three-stage propane refrigeration cycle, a closed two-stage ethylene refrigeration cycle and an open methane refrigeration cycle employing at least three flash stages and three stages of compression and wherein said methane-rich gas stream contains appreciable concentrations of C_{2+} hydrocarbons, the improvement

comprising:

(a) cooling at least a portion of said methane-rich gas stream via indirect heat exchange with a refrigerant stream from each pressure reduction stage in the propane refrigeration cycle and a refrigerant stream from the first pressure reduction stage in the ethylene refrigeration cycle thereby producing a cooled methane-rich stream;

(b) introducing said cooled methane-rich stream into an NGL recovery column at one or more feed stages for separation into a first gas stream primarily comprising relatively more volatile components and a first liquid stream primarily comprising relatively less volatile components;

(c) introducing said first liquid stream into an NGL purifying column at one or more feed stages to produce an NGL product comprising desirable less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column;

(d) condensing and subcooling said first gas stream via indirect heat exchange with at least one refrigerant stream from the ethane or ethylene refrigeration cycle thereby producing a pressurized and subcooled LNG stream;

(e) expanding said pressurized and subcooled LNG stream in one or more stages to a lower pressure to produce an LNG stream suitable for storage and at least three flashed vapor streams;

(f) compressing at least a portion of said flash vapor streams and second gas stream via a multi-stage compressor to a pressure at least as great as that existing in the NGL recovery column; and

(g) cooling at least a portion of said compressed flashed vapor stream via indirect heat exchange with at least one refrigerant stream from the propane refrigeration cycle, at least one flashed vapor stream, and at least one refrigerant stream from the ethylene refrigeration cycle thereby at least condensing said stream and thereafter introducing said stream to the top portion of said NGL recovery column as an overhead reflux to enhance recovery of less volatile components.

60. In a process for liquefying a pressurized methane-rich gas stream via a cascaded refrigeration process employing a closed two- or three-stage propane refrigeration cycle, a closed two- or three-stage ethane or ethylene refrigeration cycle and an open methane

refrigeration cycle employing two or more flash stages and wherein said methane-rich gas stream contains appreciable concentrations of C_{5+} hydrocarbons, the improvement comprising:

(a) separating the pressurized methane-rich gas stream into at least a first methane-rich gas stream and a stripping gas stream;

(b) cooling at least a portion of said first methane-rich gas stream via indirect heat exchange with a refrigerant stream from each pressure reduction stage in the propane refrigeration cycle and at least the ethylene refrigerant stream from the first pressure reduction stage in the ethylene refrigeration cycle thereby producing a cooled methane-rich stream;

(c) introducing said cooled methane-rich stream into an NGL recovery column at one or more feed stages, said stripping gas stream into the bottom section of said column, and a reflux stream into the top section of the column thereby producing a first gas stream from the top section of said column primarily comprising relatively more volatile components and a first liquid stream produced from the bottom section of said column comprising relatively less volatile components produced;

(d) condensing and subcooling said first gas stream via indirect heat exchange with at least one refrigerant stream from the ethane or ethylene refrigeration cycle and one or more flashed vapor streams from the open methane cycle thereby producing a pressurized and subcooled LNG stream;

(e) expanding said pressurized and subcooled LNG stream in two or more pressure reduction stages to a lower pressure to produce an LNG stream suitable for storage and at least two flashed vapor streams;

(f) compressing at least a portion of said flashed vapor streams to a pressure greater than the pressure existing in the NGL recovery column; and

(g) obtaining the reflux stream employed in step (c) by one of the following steps:

(i) cooling at least a portion of said compressed gas stream of step (f) via indirect heat exchange with at least one refrigerant stream from the propane refrigeration cycle and one refrigerant stream from the ethane or ethylene refrigeration cycle thereby condensing said stream;

(ii) further cooling at least a portion of said cooled methane-rich stream to at

least substantial condensation via indirect heat exchange with at least one ethane or ethylene refrigerant streams from the ethane or ethylene refrigeration cycle or at least one flashed vapor stream from the open methane cycle thereby producing a substantially condensed stream;

(iii) employing a portion of a LNG stream removed during the cooling of step (d); or

(iv) the pressurized and subcooled LNG stream of step (d).

61. A process according to claim 59, additionally comprising the step of:

(h) introducing said first liquid stream into an NGL purifying column at one or more feed stages to produce an NGL product stream comprising desirable less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column.

62. A process according to claim 60, wherein the alternatives set forth in step (g) for obtaining reflux further include:

(v)compressing at least a portion of said second gas stream of step (h) to a pressure at least as great as that existing in the NGL recovery column and cooling at least a portion said compressed second gas stream via indirect heat exchange with at least one refrigerant stream from the propane refrigeration cycle and one refrigerant stream from the ethane or ethylene refrigeration cycle thereby at least condensing said stream, or

(vi) compressing at least a portion of said flash vapor streams and at least a portion of said second gas stream via a multi-stage compressor to a pressure at least as great as that existing in the NGL recovery column and cooling at least a portion of said compressed gas stream via indirect heat exchange with at least one refrigerant stream from the propane refrigeration cycle and one refrigerant stream from the ethane or ethylene refrigeration cycle thereby at least condensing said stream.

63. A process according to claim 61, wherein cooling step (a) further comprises removing at least one liquid stream from the stream undergoing cooling and feeding said liquid stream either directly or in combination with another stream to the NGL recovery column.

64. A process according to claim 61, wherein said stripping gas stream is cooled via indirect heat exchange with the first liquid stream prior to introduction into the bottom

section of the NGL recovery column.

65. In a process for liquefying a pressurized methane-rich gas stream via a cascaded refrigeration process employing a closed three-stage propane refrigeration cycle, a closed two-stage ethylene refrigeration cycle and an open methane refrigeration cycle employing three flash stages and three stages of compression and wherein said methane-rich gas stream contains appreciable concentrations of C_{5+} hydrocarbons, the improvement comprising:

(a) separating the pressurized methane-rich gas stream into at least a first methane-rich gas stream and stripping gas stream;

(b) cooling at least a portion of said first methane-rich gas stream via indirect heat exchange with a refrigerant stream from each pressure reduction stage in the propane refrigeration cycle and at least the ethylene refrigerant stream from the first pressure reduction stage in the ethylene refrigeration cycle thereby producing a cooled methane-rich stream;

(c) introducing said cooled methane-rich stream into an NGL recovery column at one or more feed stages, said stripping gas stream into the bottom section of said column, and a reflux stream into the top section of the column thereby producing a first gas stream produced from the top section of said column primarily comprising relatively more volatile components and a first liquid stream produced from the bottom section of said tower comprising relatively less volatile components produced;

(d) condensing and subcooling said first gas stream via indirect heat exchange with at least one refrigerant stream from the ethane or ethylene refrigeration cycle and one or more flashed vapor streams from the open methane cycle thereby producing a pressurized and subcooled LNG stream;

(e) expanding said pressurized and subcooled LNG stream in three pressure reduction stages to a lower pressure to produce an LNG stream suitable for storage and at least two flashed vapor streams;

(f) introducing said first liquid stream into an NGL purifying column at one or more feed stages to produce an NGL product stream comprising desirable less volatile components from the bottom and a second gas stream comprising more volatile components from the overhead of said NGL purifying column;

(g) compressing said second gas stream and at least a portion of said flashed vapor streams via a multi-stage compressor to a pressure at least as great as that existing in the NGL recovery column; and

(h) cooling at least a portion of said compressed stream of step (I) via indirect heat exchange with at least one refrigerant stream from the propane refrigeration cycle, at least one flashed vapor stream, and at least one refrigerant stream from the ethylene refrigeration cycle thereby at least condensing said stream and thereby producing the reflux stream employed in step (c).

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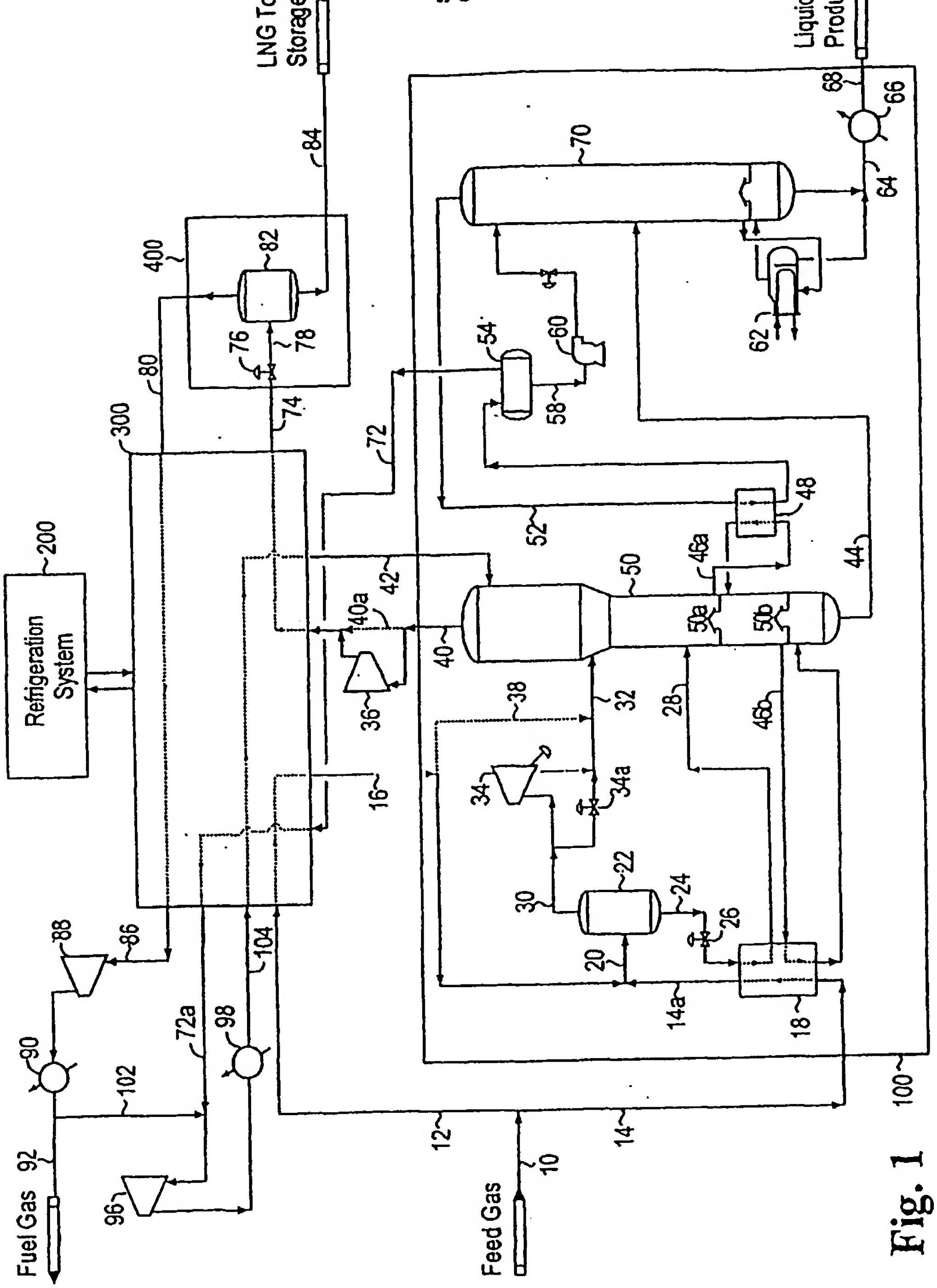
LNG To Storage
Liquid Product
Refrigeration System
Fuel Gas
Feed Gas

Fig. 1

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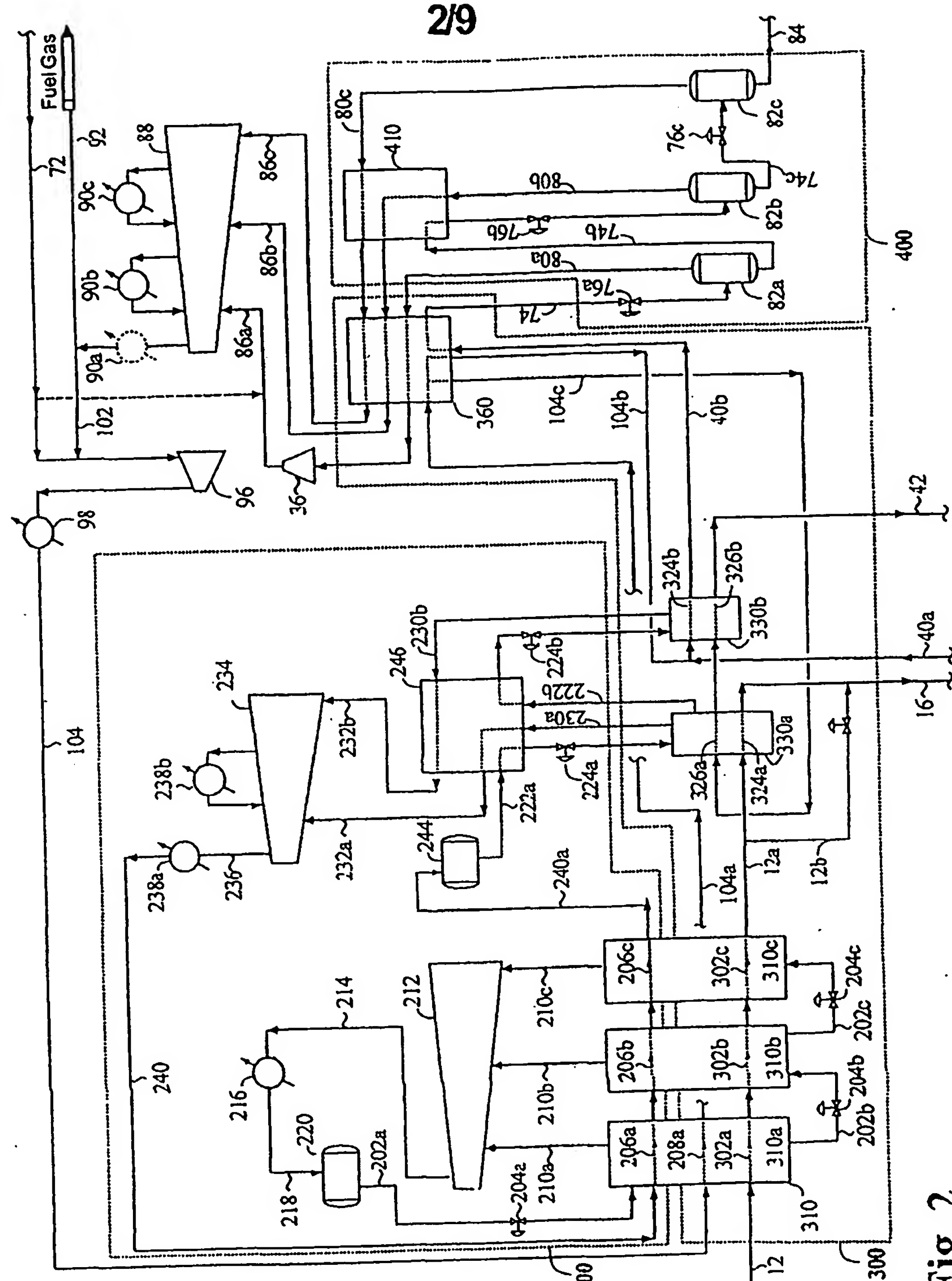
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Fig. 2

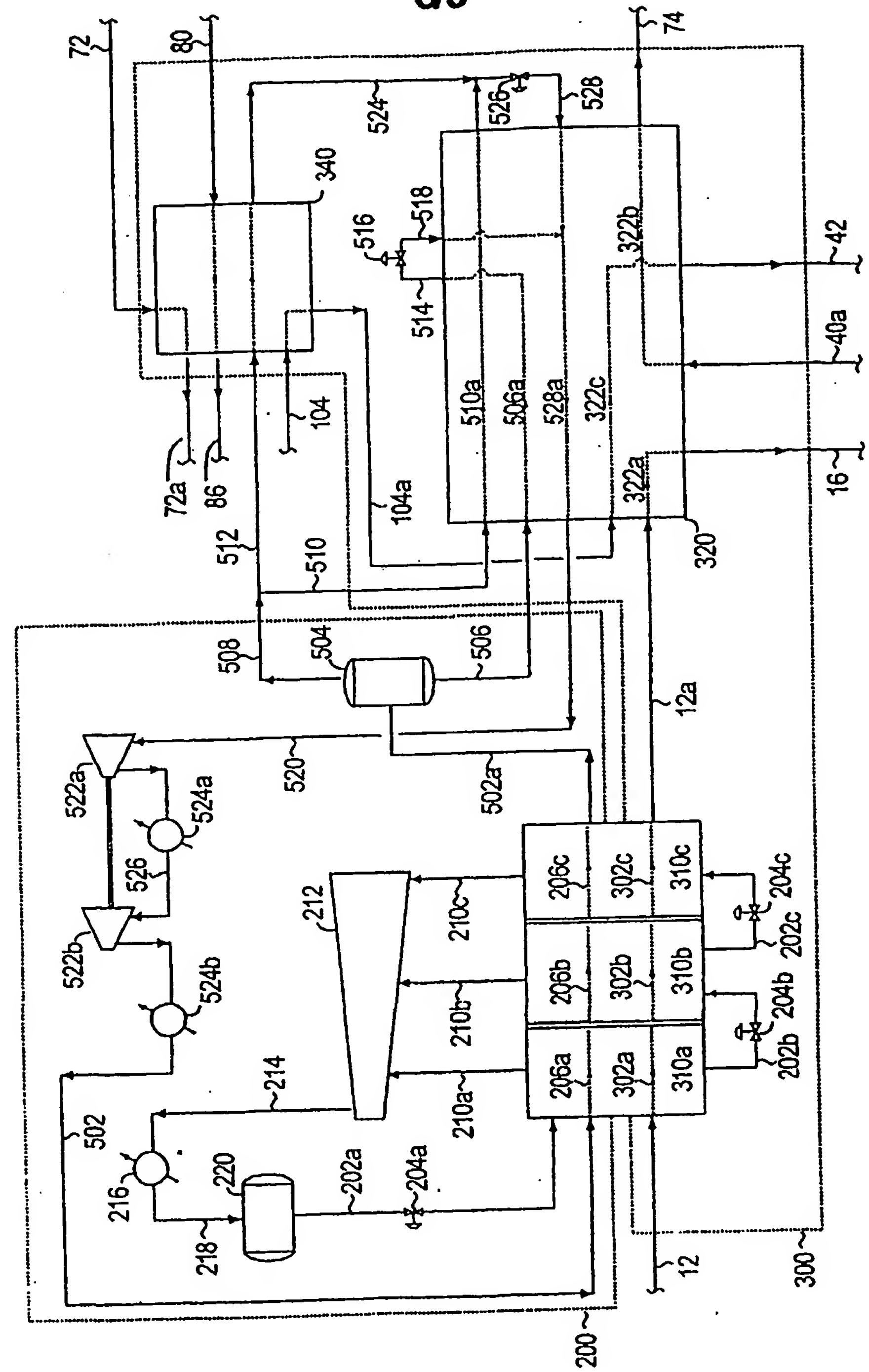
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Fig. 3

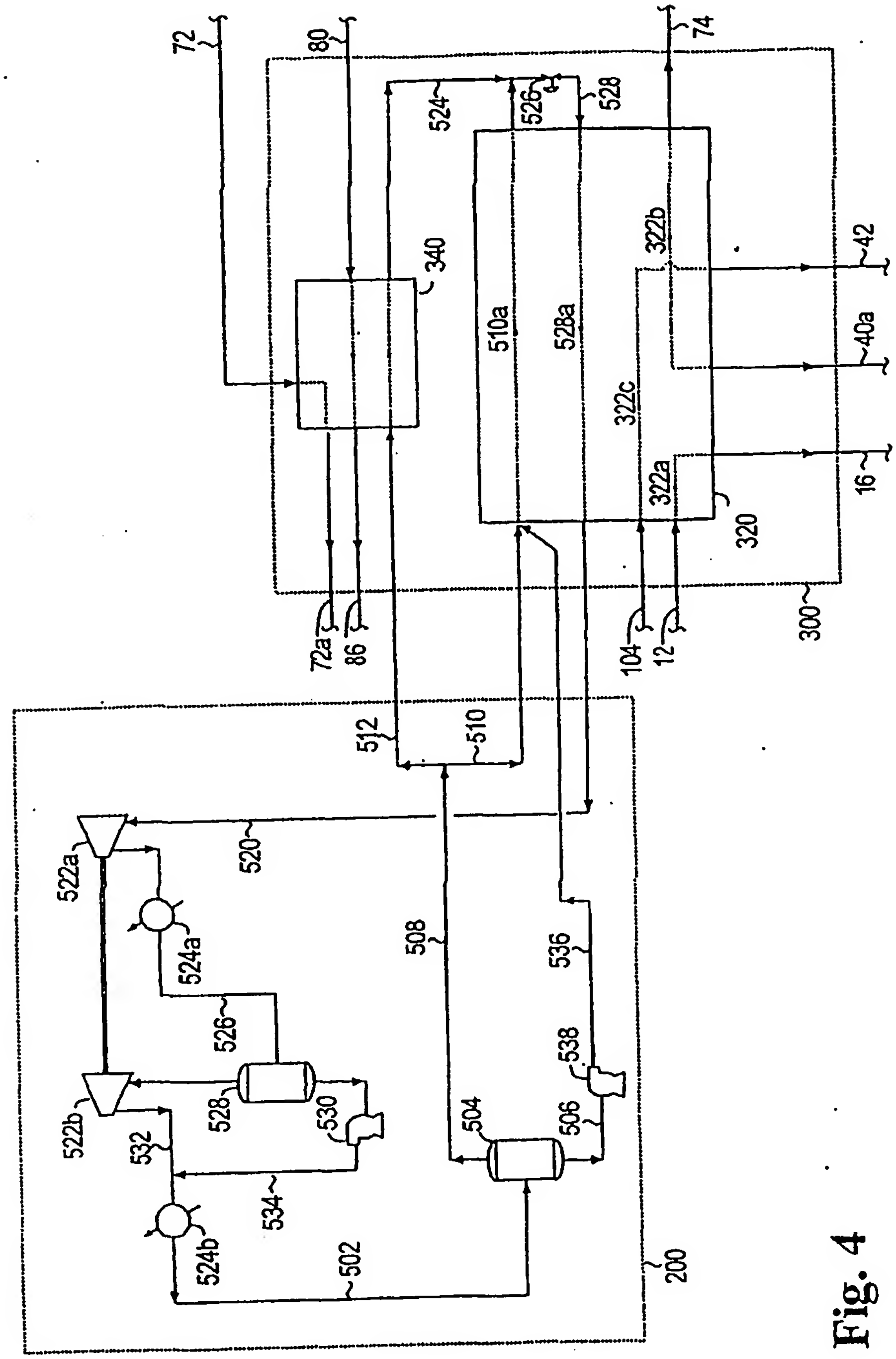
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Fig. 4

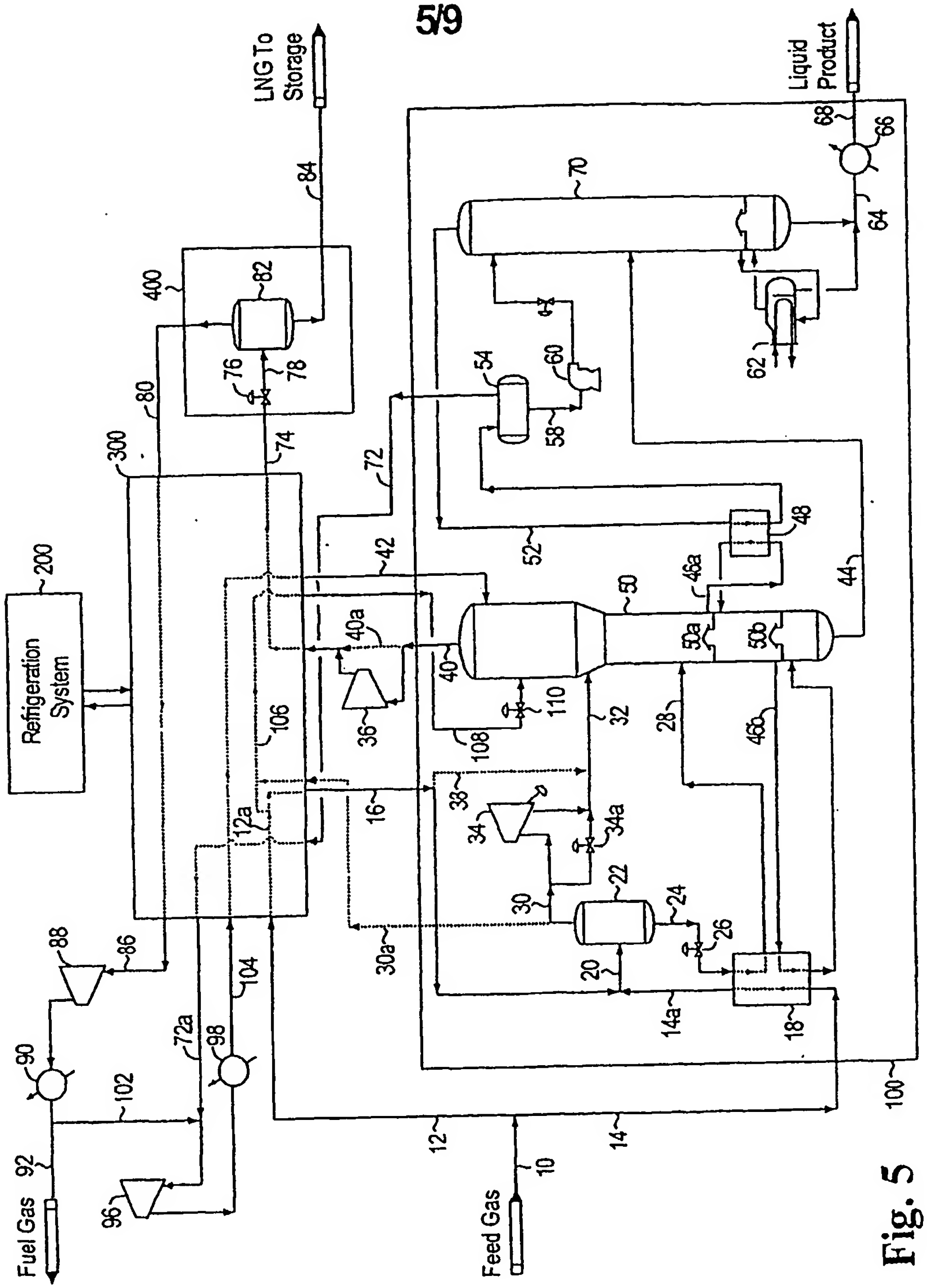

LNG To Storage
Liquid Product
Refrigeration System
Fuel Gas
Feed Gas

Fig. 5

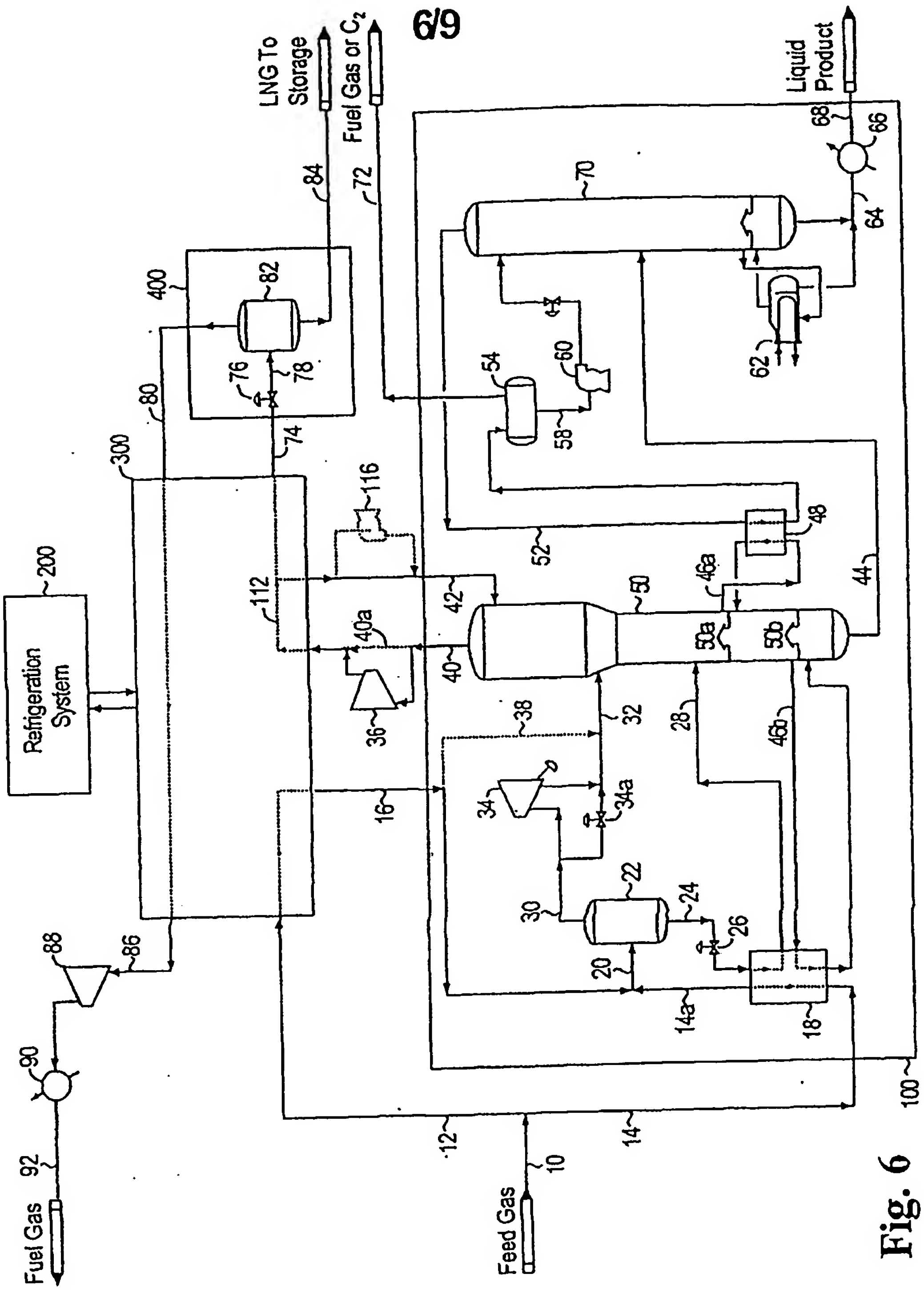

LNG To Storage
Fuel Gas or C_2
Liquid Product
Refrigeration System
Fuel Gas
Feed Gas
200
300
400
10
12
14
14a
16
18
20
22
24
26
28
30
32
34
34a
36
38
40
40a
42
44
46a
46b
48
50
50a
50b
52
54
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90
92
100
112
116

Fig. 6

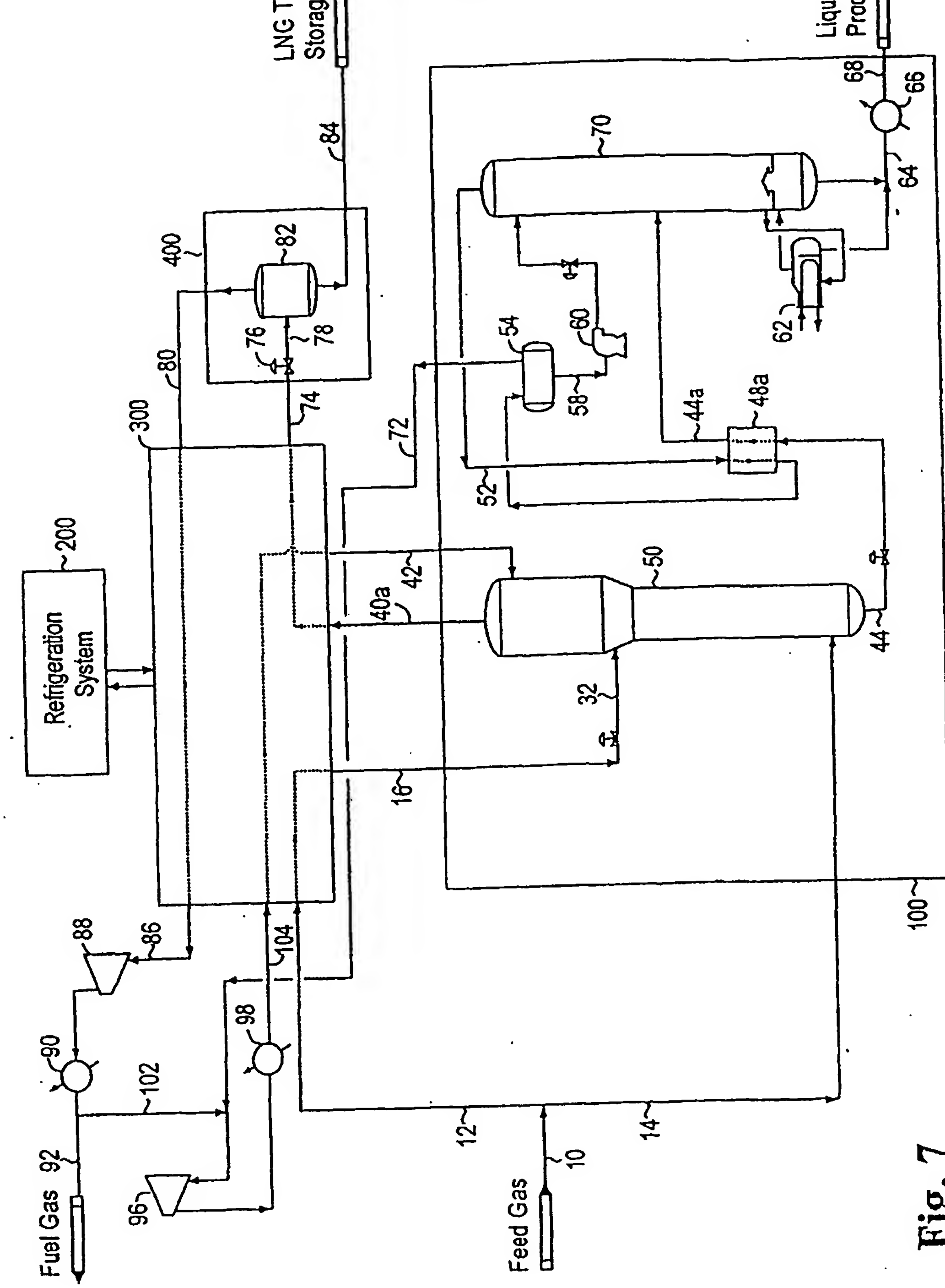

LNG To Storage
84
82
400
76
78
80
74
300
Refrigeration System
200
72
54
60
58
52
44a
48a
70
Liquid Product
68
66
64
62
50
42
40a
44
32
16
100
86
88
90
102
92
Fuel Gas
98
104
96
12
10
14
Feed Gas

Fig. 7

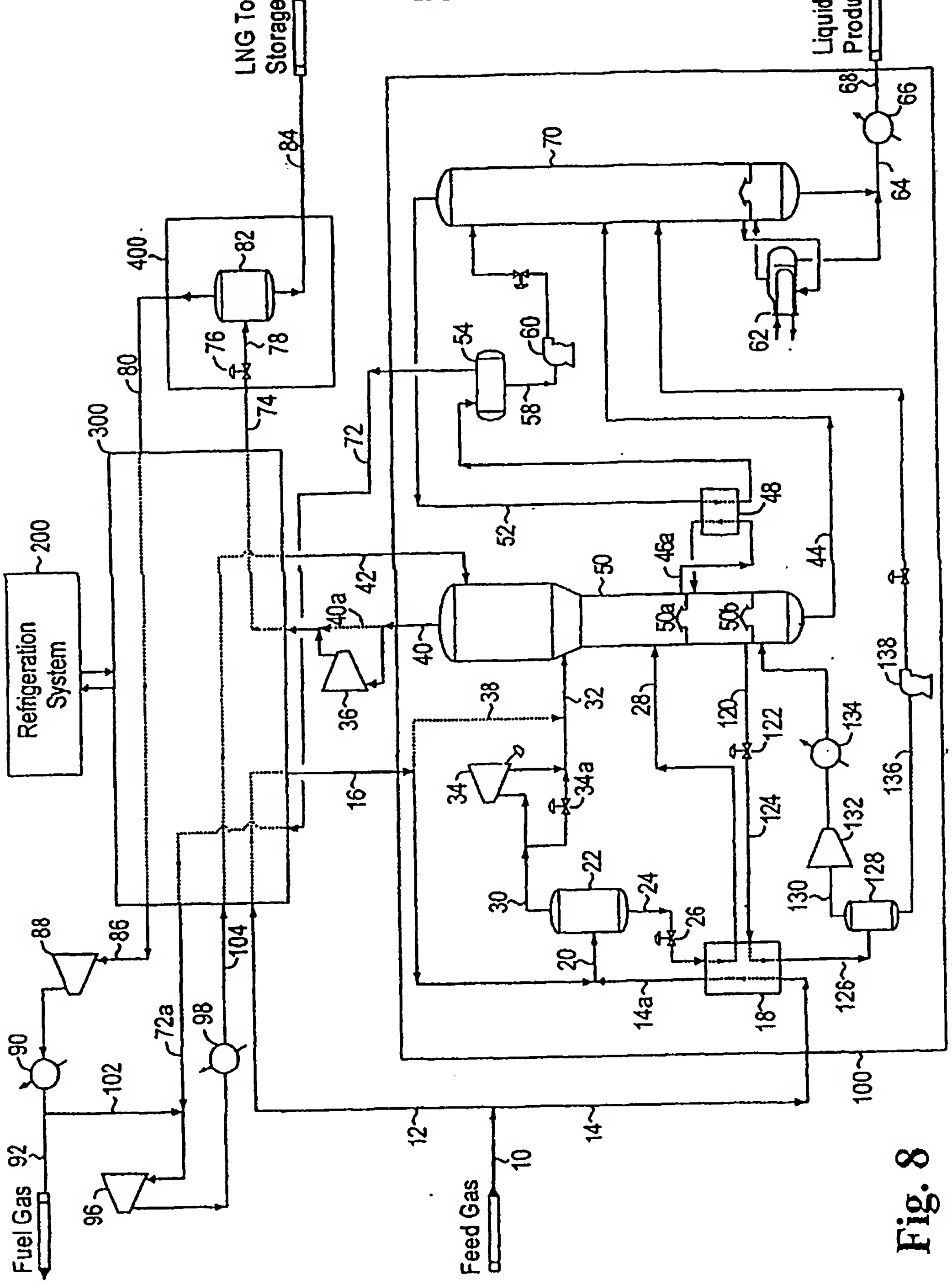
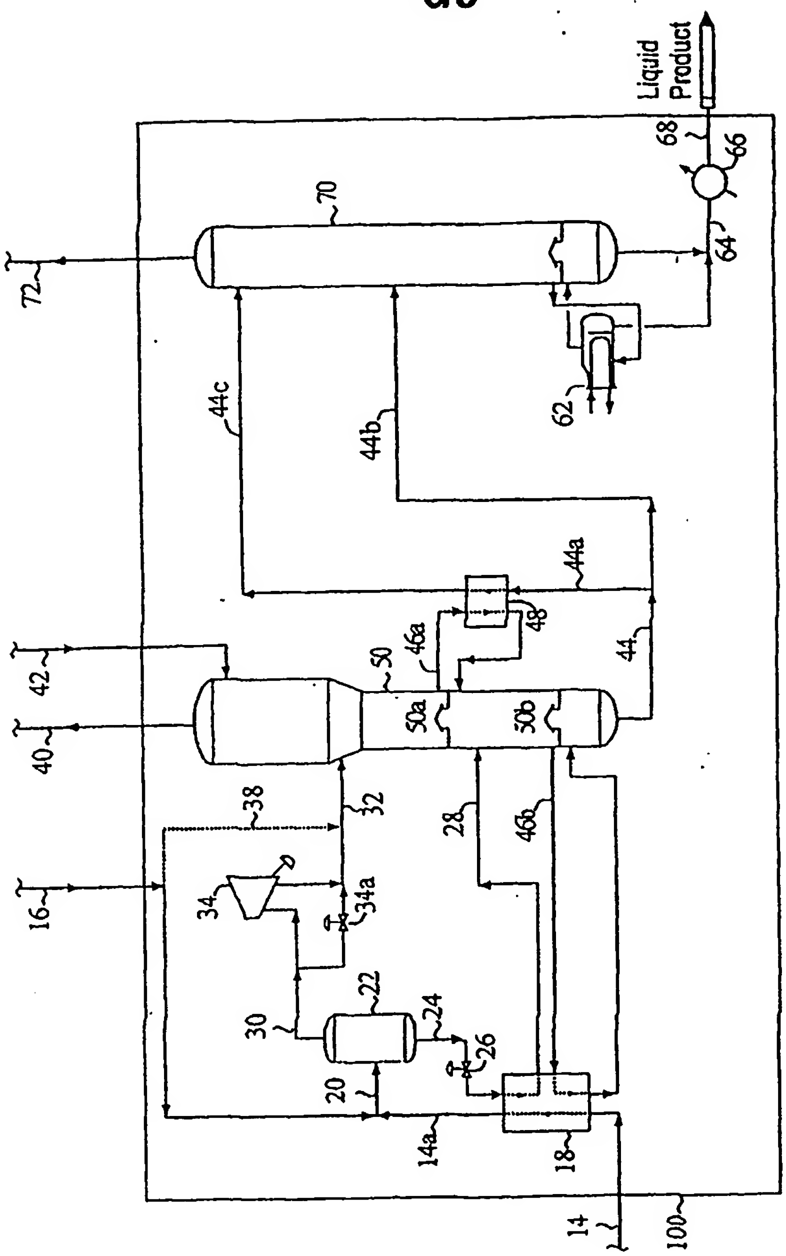

LNG To Storage
Liquid Product
Refrigeration System
Fuel Gas
Feed Gas

Fig. 8



Liquid Product
68
66
64
70
72
62
44c
44b
44a
44
48
46a
46b
50
50a
50b
42
40
38
32
28
16
34
34a
22
30
24
26
20
14a
18
14
100

Fig. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/15721

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : F25J 3/00, 1/00
US CL : 62/630, 612, 614
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 62/630, 612, 614, 611, 613, 617, 619, 620

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
None

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
None

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,799,507 A (WILKINSON et al) 01 September 1998 (01.09.1998), see figure 1.	1,3,4
X	US 4,690,702 A (PARADOWSKI et al) 01 September 1987 (01.09.1987), see figures 1-3.	1,3,4,6 and 7
X	US 5,291,736 A (PARADOWSKI) 08 March 1994 (08.03.1994), see entire document.	1,3,4,6,7,11,13-15,24,26,29
Y		35-40,42-52
X,P	US 6,116,050 A (YAO et al) 12 September 2000 (12.09.2000), see entire document.	1-7,11-17,24-27,29,30
Y,P		35-40,42-52
Y	US 5,669,234 A (HOUSER et al) 23 September 1997 (23.09.1997), see entire document.	35-40,42-52
A	US 3,724,226 A (PACHALY) 03 April 1973 (03.04.1973), see figures 1 and 2.	1-65
A	US 4,065,278 A (NEWTON et al) 27 December 1977 (27.12.1977), see figure 1.	1-65
A	US 4,430,103 A (GRAY et al) 07 February 1984 (07.02.1984), see entire document.	1-65
A	US 5,615,561 A (HOUSHMAND et al) 01 April 1997 (01.04.1997) see entire document.	1-65
A	US 5,950,453 A (BOWEN et al) 14 September 1999 (14.09.1999), see figure 3.	1-65

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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12 July 2001 (12.07.2001)

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